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Lubrication Cooling Troubles and Remedies

By

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LUBRICATION

LUBRICATION AND COOLING TROUBLES AND REMEDIES

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INTERNATIONAL TEXTBOOK PRESS
Scranton, Pa.

84490

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LUBRICATION

Serial 3141

Edition 2

LUBRICANTS AND THEIR APPLICATION

LUBRICANTS

PROPERTIES OF LUBRICANTS

1. Object of Lubrication.—Lubrication consists in introducing some substance, either liquid or solid, such as oil, grease, or graphite, between two rubbing surfaces to reduce the friction and the wear that otherwise would occur. No matter how smooth a metallic surface may appear to the sight or to the touch, it is, in reality, covered with very minute projections or ridges and hollows. These are readily seen under a microscope. Hence, when two clean metallic surfaces are placed together, and motion is imparted to one or both of them, so as to cause one to slide or roll on the other, these little ridges engage one another, or interlock, with the result that some of the projections are torn loose from each piece. It is this tearing away or abrading of the metal that causes wear, and the resistance thus offered is known as *friction*.

When a lubricating substance, such as oil, grease, or graphite, is put between the two surfaces, it fills the little hollows and forms a thin film, or layer, that prevents the metals from actually touching each other except at the points of the highest ridges. As a result there is less wear, since fewer ridges are torn loose, and this means less friction also. Proper lubrication is the most important factor in the maintenance and operation of any type of mechanically operated appliance. Machinery, as in use today, cannot be operated without lubrication, and will not prove serviceable for any length of time with improper lubrication.

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2. Requirements of Lubricants.—The origin of lubricants is not so important to the engineer as their lubricative properties and their power to resist decomposition, vaporization, and combustion under the action of heat; especially is this the case with cylinder oils and valve oils. The value of a lubricant depends largely on its internal friction, or *absolute viscosity.* Absolute viscosity cannot be measured without elaborate and expensive laboratory apparatus. Hence, as an alternative, this test is customarily replaced by one that measures the resistance to flow of any given oil. This resistance bears a definite relation to the absolute viscosity and is termed the *kinematic viscosity,* and it is this property, more generally known as the viscosity of the oil, that enables it to hold two bearing surfaces apart, even under heavy loads, thereby preventing metallic contact and wear. This property also has a considerable influence on the temperature at which a bearing will run.

Several commercial instruments are available for making a viscosity test. One of these, the Saybolt viscosimeter, is adopted as standard in this country. By the use of this instrument, the viscosity of any oil is measured by the time in seconds that it takes for a given quantity of oil to flow from a certain size of opening at a certain temperature. The oil under test is then said to have a viscosity of, say, 300 seconds Saybolt, depending on the time consumed by the oil in passing through the orifice of the viscosimeter. An oil of high viscosity will take a longer time to flow than one with low viscosity, the quantity and temperature of the oil being the same in both cases. It will be evident that a change in temperature of the oil has considerable influence on the viscosity measurement.

3. Desirable features of a good lubricant are: It should reduce friction to a minimum. It should be free from acids and free alkalies, or, in other words, it should be neutral, and of uniform consistency. It should not become gummy, rancid, or otherwise altered by exposure to the air and it should be odorless. It should stand low temperatures without solidifying or depositing solid matter, and high temperatures without breaking down. It should be entirely free from grit and all foreign mat-

ter. It should be especially adapted to the speed and pressure of the rubbing surfaces on which it is to be used; the question of cost is also a consideration. All first-class lubricants possess these properties to a greater or less degree, and each of them is adapted to its own particular class of work.

4. Heavy oils are generally considered to rank the highest in viscosity; this is not always the case, however. Some oils of high specific gravity rank lower in viscosity than others of a lower specific gravity, hence the lubricating qualities of an oil cannot always be judged accurately by either its viscosity or specific gravity. Then, again, different manufacturers of lubricants have different standards and names for practically the same grade of oil. Furthermore, lubricants that may be very satisfactory for heavy journals might not do at all for light journals, and those that answer well for journals and guides would be very objectionable in cylinders and valves. The character of the service of the lubricated part also determines the grade of oil to be selected; for example, a bearing of an engine running at very high speed requires an oil of lighter body than does a slow-speed unit, for the reason that an oil of high viscosity would become highly heated owing to the high internal friction.

5. Selection of Lubricants.—Though there are numerous tests for determining the various properties of lubricants, they, as a rule, involve the use of equipment beyond the reach of the average engineer in ordinary engine-room practice. Some of the simpler tests will be given later. The best method of procedure in obtaining proper lubrication of the machinery in a plant is to apply to any one of the leading oil refining companies for advice from their lubricating department, which is maintained expressly for this purpose. If the engineer is obliged to select his lubricating oil himself, he should first procure from a reputable dealer several samples of oil or grease that in his judgment are best suited to the machinery he has in charge, taking care to select light-bodied oils for high-speed machinery and to grade his selections down accordingly to suit the size and weight of the journals and the work they have to do. He should examine these samples very carefully in every possible way and compare one with the other; he should note their color and transparency; rub some of each between the fingers and thumb or on the palm of the hand; note whether the sample is smooth and oily and contains no grit; pour a few drops on a sheet of tin or a piece of glass and hold the tin or glass at different angles and note how the oil flows and whether it leaves any residue in its track; examine it with a strong magnifying glass for foreign substances; smell it, and if it is rancid or has a very offensive odor, reject it. If the engineer persists in this practice, it will not take him long to learn how to distinguish between the different grades and qualities of lubricants, which will enable him to select the one that will best serve his purpose.

6. The selection and care of lubricants for a certain type of engine should be carefully considered and every effort should be made to practice economy in the use of the lubricants selected. This may be done by measuring out the quantity of lubricant to be used in such a manner that the amount used by each oiler can be checked. When an excessive amount of oil is being used, the cause should be investigated at once and the trouble corrected. Waste of lubricants should be avoided, both on the score of economy and of cleanliness of operation. The importance of reducing to a minimum the quantity of oil fed to the bearings and other parts of an engine cannot be overestimated; this is especially true in the case of a steam engine the exhaust steam of which is used as feedwater, as the presence of oil in the feedwater is liable to be the cause of the formation of sludge in the boiler. Methods of lubrication by which the oil is not delivered with certainty and in measured quantity to the parts to be lubricated, generally result in insufficient lubrication and poor piston seal, or an excessive amount of oil in the condenser and feedwater.

7. An oil properly selected for the lubrication of a given mechanism should be of such quality that the cohesion will be strong enough, at the highest operating temperature met with in practice, to prevent the rupture of the oil film between the parts, and yet the viscosity must not be so great as to cause a loss in power in overcoming the internal friction in the oil itself.

The choice of a suitable oil lies between an oil so heavy that it will not break down and one that is so light that it will readily flow with the least resistance but that may not be able to maintain an unbroken separating film. The basic principle of correct lubrication of any piece of machinery involves not only the selection of the most suitable lubricant to meet the prevailing conditions of operation, but also the method of application of the lubricant as a separating agent, or film, between the moving and stationary parts. There is no economy in buying cheap lubricants; they cost less per gallon, but it takes more gallons to do the required work. Now that excellent oil filters are to be had, enabling the used oil to be filtered and used over again, there is no necessity for using cheap oils.

8. **Classification of Lubricants.**—Lubricants may be divided into three distinct classes, viz., *animal, vegetable,* and *mineral.* The name of each designates its origin. There are also lubricants that are composed of a combination of two or more of the above primary classes, which practically form another, or fourth, class. The oils here enumerated are known as fluid lubricants. In addition, various greases and other solid lubricants are used for engine lubrication.

FLUID LUBRICANTS

9. **Animal Oils.**—Animal oils are derived from the fats of animals and fish. Those that are used as lubricants in internal-combustion engine practice are sperm oils and porpoise oils, which are used, principally in a highly refined state, for oiling indicators and other delicate mechanisms, such as recording gauges, pyrometers, etc. Other animal oils that are used, though rarely, are whale oil, lard oil, tallow oil, and neat's-foot oil.

10. **Vegetable Oils.**—Vegetable oils are obtained by pressing the seeds or fruit of such plants as yield oil in commercial quantities, and removing the suspended fibers by treatment with acids. Oils made from rapeseed, cottonseed, olives, cocoanuts, and castor beans are the vegetable oils used to some extent.

11. **Mineral Oils.**—Mineral lubricating oils are distilled from bituminous shale and from the residuum of crude petroleum

after the volatile oils and illuminating oils have been distilled off at various temperatures up to 572° F. The products of the petroleum still, when heated to temperatures above 572° F., are the lubricating oils. These oils are graded according to their specific gravities, their viscosities, and their flash and burning points. The color of a mineral lubricating oil is not always an indication of its value as a lubricant; it merely indicates the amount of filtration and bleaching it has received in the refining process. A dark-colored oil may be better than a light-colored one; therefore, in selecting a mineral oil, too much stress should not be laid upon its color.

12. Characteristic Differences Between Mineral and Fatty Oils.—Mineral oils are fundamentally different from animal and vegetable oils, or the so-called fatty oils. On the application of heat, mineral oils can be distilled with comparatively little decomposition; on the other hand, when animal or vegetable oils are heated, they decompose instead of distilling. Hence, such oils are called *fixed oils,* because they cannot be distilled without decomposing.

Mineral oils are composed primarily of carbon and hydrogen; that is, of hydrocarbons. Animal and vegetable oils, however, contain oxygen, in addition to carbon and hydrogen, as an essential part of their composition. Still another interesting characteristic of the fixed oils is that they show a greater tendency to form an emulsion with water than do the mineral oils.

Further, all animal and vegetable oils combine, to a certain extent, with the oxygen of the air. This fact is one of the great disadvantages to the more extensive use of fatty oils as lubricants. The gradual oxidation of fatty oils under conditions of lubrication, produces acids that attack the metal surfaces and cause pitting and corrosion to take place; and, in addition, forms resins and gums that offer resistance to motion and also tend to stop up the oil passages. This partial or complete closing of the oil passages hinders or prevents the oil from reaching the bearings, and causes excessive heating and burned-out bearings.

13. Advantages of Mineral Lubricating Oils.—Although it was early recognized that fatty oils were excellent lubricants, and that they apparently had more so-called oiliness than mineral lubricating oils of the same viscosity, nevertheless the more extensive use of petroleum lubricants continued to develop. The high cost of fatty oils and their oxidizing tendency as compared with mineral lubricating oils, together with the marked growth of the petroleum industry and the improvements made in processes of refining lubricating oils, were outstanding factors in the growth of the use of mineral oil, in spite of the fact that an animal or a vegetable oil possesses the property of being able to wet the bearing surfaces more efficiently than a petroleum oil. In other words, because lubricating oils made from crude petroleum are relatively cheap, do not emulsify easily, and do not oxidize so readily as fatty oils, practically all lubricants used in the circulation systems and splash systems of modern engines consist of pure mineral oils of the highest quality.

14. In general, mineral oils are petroleum products possessing characteristics usually expressed in terms of specific gravity, cold test, flash point, fire point, and viscosity; sometimes a color test is included. These specifications indicate the oil properties in terms of laboratory measurements and are used by refiners to assure uniformity in the production of certain brands from given crudes. Mineral oils may be classified as steam-cylinder oils, bearing oils, and special oils. Cylinder oils are residual products in the distillation of crude petroleum. They are used for the lubrication of valve mechanisms and cylinders of steam engines. Bearing oils are distilled from crude petroleum but are more highly refined than cylinder oils and they are sometimes specially treated. Special oils are other manufactured petroleum products, usually made for special purposes of lubrication, such as the lubrication of air-compressor cylinders. Occasionally, blended lubricants are used. *Blending* is the term usually applied to the process of mixing together two or more petroleum stocks in the manufacture of lubricants, and should not be confused with *compounding.* Compounding is the name generally given to the process of mixing together an animal, a vegetable, or other fatty oil and one or more petroleum oils in making a particular grade of lubricating oil. Blend-

ing is sometimes resorted to for the purpose of making a lubricant suitable for some particular purpose, as when the lubricant must meet certain specifications such as those of viscosity, color, cold test, flash point, and fire point. Compounded oils are often used as steam-cylinder oils, especially if the steam contains a comparatively large percentage of moisture, as the emulsion formed with the water sticks to the wearing surfaces. Almost all steam-cylinder oils at present are therefore compounded with about 5 per cent. of lard oil, even when superheated steam is used, as the steam during expansion may reach the condensation point and moisture appears. One disadvantage of the use of compounded oil is that the emulsion formed by the oil with water will coat the condenser tubes with a heat-insulating film. In case the condensed steam is returned to the boiler as feedwater, the emulsion may cause the boiler to foam. Provision must, therefore, be made to extract the spent oil from the exhaust steam in all installations in which the exhaust is used as boiler feedwater or is run into a condenser.

SEMISOLID AND SOLID LUBRICANTS

15. Use of Greases.—As a general rule semisolid lubricants, or greases, are used in places where, by reason of design, a lubricating oil would not be satisfactory or would break down. They find general use in high-pressure bearings where the journal speed is low, and where it would be difficult to maintain an oil film, as in ball bearings.

16. Definition of Grease.—Grease is a soap-thickened mineral oil. It is a manufactured product, the general characteristics of which can be changed exactly to meet conditions. Grease is a lubricant of the semifluid or semisolid type, as distinguished from mineral lubricating oil, which is a fluid lubricant, and graphite, which is a solid lubricant. Grease may also be considered as being an intimate emulsion of mineral lubricating oil and soap, the latter being made by saponifying a fatty animal or vegetable oil with soda, potash or lime. Horse oil, beef tallow, mutton tallow, lard oil, and acidless tallow oil are among the animal oils used in making greases. Cottonseed oil, soya-bean oil, corn oil, palm oil, cocoanut oil, and peanut oil are the vegetable oils that frequently are utilized.

17. **Properties of Grease.**—The thickness of grease varies from the consistency of a thick liquid to that of a hard soap. The lubricating properties of any grease depend to a large extent on the lubricating value of the oil used in making it and are not usually available for the reduction of friction in a bearing until the temperature of the bearing has become sufficiently high to melt the soap and thus liberate the oil contained in the grease. The soap adds little, if anything, to the lubricating properties of the grease.

18. Since a grease must melt before the lubricant is available, a grease that melts at a temperature sufficiently low to keep the bearing from being damaged must be chosen. The melting temperature depends both on the amount of soap in the grease and on the kind of soap. The flash point and the fire point of a grease are usually the same as those of the oil contained in it.

Both grease and oil mixed with white lead are frequently used in places where the temperature around the bearing is very high or very low. When the temperature of the surrounding air is high, a grease suitable for use in the bearing must have a melting point only slightly above that of the air, in order that the bearing will not become too hot before the grease melts. Furthermore, if oil, by itself, is employed, neither it nor the oil used in the grease should flash at a temperature less than 100° above the air temperature. If the bearing is exposed to very low temperatures, an oil or a grease of such consistency that it will not become hard at the temperature of the air must be used.

Solid materials such as graphite and soapstone are sometimes added to grease to harden it. Graphite also adds valuable lubricating qualities to the grease or oil with which it is mixed, providing the graphite is not used in such quantities as to make a mud and clog the bearing. Graphite smoothes the surfaces of the bearing by filling up the hollows and thus reduces both friction and wear. Other fillers sometimes used in the manufacture of greases include resin, resinous oils, wax, talc, powdered mica, sulphur, clay, and asbestos.

19. Classification of Greases.—Almost all greases that are now marketed, with the exception of certain greases of a special type, can be classified as cup greases, fiber or sponge greases, cold-set rosin or axle greases, railroad-engine greases, and double-decomposition greases. Cup and sponge greases belong to the class known as hot-set greases, since the application of heat is necessary to their manufacture. Axle and railroad-engine greases are known as cold-set greases, since little or no heat is needed to make them.

20. Cup Greases.—Cup greases, or boiled greases, are used in larger quantities for bearing lubrication than any other type of grease. Nearly all cup greases are lime-soap greases and are made by saponifying a fatty oil with slaked lime. Greases of this type have a smooth, homogeneous feeling, when the finger is passed through the grease, and they are insoluble in water. They should be bright, transparent or nearly so, be free from soap lumps, oil pockets or separations of any kind, and, in addition, should be perfectly uniform and neutral. Cup greases are made with varying consistency, the grades usually ranging from a so-called No. 00, which is the most fluid, to a No. 6, the heaviest. Their soap content varies, as a general rule, between 10 and 26 per cent.

21. Fiber, or Sponge, Greases.—Sponge, or fiber, greases are boiled greases of the soda-soap type made by saponifying fats and fatty oils by means of caustic soda. The soaps thus made are soluble in water, and for this reason fiber greases are not intended for use under water. These greases are characterized by their spongy nature and by their stringiness. Sponge greases are soft to the touch and since they are boiled, they contain only a faint trace of water. They have a very high melting point, due to the soda soap that they contain; they have a low coefficient of friction, and they form a very strong lubricating film. In almost all cases, greases of this type are neutral and do not leave gummy deposits on the bearings. If properly made, they are good lubricants, but they are apt to contain either an excess of alkali or an excess of acid; in either case they are liable to be injurious to the bearings. Free acids or alkalies may be detected by the litmus-paper test, as explained in a later article. Mineral oil is added in variable proportions to the batch during the process of manufacture to make a grease of any desired consistency. In grading sponge greases, a No. 0 grease is of the hardest consistency and a No. 3 grease, the softest. Cup greases, on the other hand, usually have just the opposite classification, a No. 0 grease being more fluid and having a softer consistency than any grease above it in the scale.

The melting points of lime-soap greases vary from 140° F. for that of the softest consistency to 237° F. for that of the hardest consistency. In the case of soda-soap greases the melting temperatures vary from 172° F. for the softest grade to 350° F. for the hardest grade. The melting temperatures given are approximate values only, as different makes of greases of the same consistencies differ somewhat in melting points. Some very hard greases have a melting point of 400° F.

22. **Cold-Set Rosin or Axle Greases.**—Cold-set rosin greases, usually known as axle greases, constitute the cheaper grades of semisolid lubricants required for rough duty. They contain the calcium soap of rosin oil and may be identified by their rosin odor. They are made by mixing while cold, the proper proportions of mineral oil, rosin oil or a mixture of rosin and rosin oil, and slaked lime. Axle greases are unfit to use for lubrication of bearings.

23. **Miscellaneous Greases.**—Of the remaining types of greases the most commonly known are the railroad-engine greases and the double-decomposition greases. The raw materials that enter into the manufacture of railroad-engine greases are fats or fatty oils, such as hard tallow or tallow oil, cylinder stock, caustic soda, fine graphite and dye solution. Double-decomposition grease, also known as castor machine oil, is a mineral lubricating oil thickened usually with aluminum soap. The greases just named are not intended to be used with close-fitting bearings and are therefore of little interest to the engineer in charge of an engine.

24. Miscellaneous Solid Lubricants.—The solid lubricants are: *graphite, soapstone, sulphur, talc,* and *white lead.* Of these, only graphite and white lead have actual lubricating qualities.

25. Graphite and White Lead.—Flake graphite, properly pulverized, is an excellent lubricant for engine bearings. Amorphous graphite contains grit in the form of clay or silica, and should not be used as a lubricant. The powdered and flake graphites are used to mix with greases for heavy journals and also to mix with the ordinary engine oils to cool a hot bearing. When graphite is used as a lubricant, the journal becomes covered with a thin coating of graphite, which reduces friction to a minimum.

White lead is one of the very best materials to use on a hot bearing, or in wearing in a troublesome bearing. Mixtures of graphite and oil, such as *oil dag* and others, are also frequently used for this purpose.

26. Mica, Soapstone, and Sulphur.—Mica and soapstone are sometimes used in powdered form mixed with oils and greases to improve the lubricating qualities for heavy and hot journals. All three substances are abrasives, however, and their use should be avoided wherever possible. Sulphur mixed with lubricating oil is used to grind down bearings after they have become heated. Sapolio, Bon Ami, and similar commercial compounds are also used for this purpose.

TESTS OF LUBRICANTS

27. Laboratory Tests of Lubricants.—Laboratory tests of engine lubricants include tests for viscosity, flash point, fire point, cloud point, pour point, carbon residue, emulsibility, and demulsibility. Tests for specific gravity of lubricating oils do not reveal the lubricating value or quality of such oils and are therefore rarely made. All tests enumerated in the foregoing have been adopted by the leading institutions in this country, including the American Petroleum Institute, the American Society for Testing Materials, and others. The operating engineer is seldom in a position to make elaborate tests of lubricants; the main value of such tests is that they furnish a check to specifications of the oil purchased. In many cases, however, the operator can make simple practical tests of the lubricating oil used. In giving the following simple tests of lubricants, there is no pretense that they are accurate in determining the commercial values of lubricating oils but they will serve to guide the engineer in the selection of his lubricants; besides, they have the merit of being applicable in ordinary engine-room practice.

28. **Apparatus for Simple Tests.**—The pieces of apparatus required to make these tests are few and inexpensive. They consist of an ordinary tin or iron pan 8 or 10 inches in diameter and 3 or 4 inches deep; a metal cup about the size and shape of an ordinary tumbler; a high-grade thermometer that will measure at least 500° F.; several quarts of clean white sand; a half-dozen clear, white glass $\frac{1}{2}$-pint bottles; a large sheet of tin or plate of glass, preferably the latter; a sheet each of red and blue litmus paper; a common thermometer; a quart of gasoline; a few pounds of ice; a pound or two of rock salt and about the same quantity of sal soda (washing soda); a small iron boiler or saucepan; a small quantity of caustic soda or concentrated lye; a pane of glass painted black on one side with a mixture of shellac varnish and lampblack; and a small tin funnel.

29. **Tests for Acids and Alkalies.**—Place a small quantity, say a teaspoonful, of the oil or grease to be tested in five or six times its bulk of boiling water, and dip into it a piece of red litmus paper; if the litmus paper remains red after having been soaked in the mixture for a considerable length of time, the oil or grease is *acid*. If the color of the paper turns to dark blue quickly, the oil is *alkaline*. If it changes color very gradually to a light blue, the oil is *neutral*. As a check on the above test, try the mixture with a piece of blue litmus paper in the same way. If the color of the paper does not change, but remains dark blue, the oil is alkaline. If the paper turns red quickly, the mixture is acid; but if the paper changes very gradually to a pale red, the solution is neutral.

Before this test is made the water to be used must first be tested with litmus paper to see whether any discoloration of the paper will result. It may be that the water itself is slightly acid, in which case the oil test would be of no practical value.

Another practical test for the presence of acid in lubricating oil consists of dissolving as much phenolphthalein as will cover a 10-cent piece in about 6 ounces of methylated spirit (10 parts by volume ethyl alcohol to 1 part methyl alcohol). To the solution is added a weak caustic-soda solution, by drops, until the mixture takes on a faint reddish tint. Next, a small quantity of the lubricating oil to be tested is added to the mixture and the sample is well shaken. If any acid is present in the oil the reddish color of the mixture will disappear.

30. Test for Viscosity.—Pour a few drops of each sample of oil upon the large sheet of tin or glass while the sheet is perfectly level, then raise one end of the sheet gently about 1 inch and support it in that position; watch the race of the drops of oil down the inclined plane. The oil that reaches the bottom of the plane *last* ranks highest in viscosity. Of course, this is only a comparative test, but it will enable the operator to select from a number of samples the oil best adapted to his purpose.

Accurate laboratory tests for the determination of the viscosity employ an instrument, known as a Saybolt viscosimeter, consisting of a container from which a certain quantity of the oil to be tested is allowed to run out through an opening, or orifice, of standardized dimensions in the bottom. The time, in seconds, required for a definite amount of the oil, usually 60 cubic centimeters, to pass through the orifice, while at a specified temperature, is taken as the viscosity. For example, when it is stated that a certain oil has a viscosity of 30 seconds Saybolt at 100° F., it signifies that 30 seconds are required for 60 cubic centimeters of the oil to flow through the measuring orifice of the Saybolt viscosimeter, the temperature of the oil during the test being maintained at 100° F.

31. Flash and Burning Tests.—Although the tests for flash and burning, or fire, points are more properly made in a regular testing laboratory, the engineer may readily check these items in the specifications of a lubricating oil in the following manner: Pour some of the oil that is to be tested into the metal cup until it is nearly full; place the cup in the pan and surround the cup with sand until the pan is filled; place the pan and contents on a hot stove, over a gas jet, or in any other convenient place for heating it; immerse the bulb end of a high-grade thermometer in the oil in the cup and watch the rise in temperature; when it reaches 300° F., pass a lighted match slowly across the top of the cup; repeat this for every two or three degrees rise in temperature until the vapor arising from the heated oil ignites with a flash, then note the temperature indicated by the thermometer when the flash is first observed; it is the *flash point.* Continue the test until the oil ignites and burns on the surface. When that occurs the reading of the thermometer gives the *burning point.* This is also known as the *fire point.* The results obtained by these practical tests are from 10 to 15 degrees higher than those obtained by the laboratory tests.

32. Cold, or Chill, Test.—Partly fill the metal cup with a sample of oil; place the cup in the pan; fill the pan around the cup with cracked ice mixed with rock salt and sal soda; cover the apparatus over with a piece of bagging or blanket and keep it covered until the oil in the cup is congealed; then remove the freezing mixture from the pan and fill the pan with hot water; when the oil in the cup commences to melt, immerse the bulb of a thermometer into it and note the temperature; it is the *congealing point.*

The congealing point of an oil is of interest to the refrigerating engineer, as lubricants used for the piston rods and cylinders of ice machines should have a low cold test, or congealing point, to prevent the oil from congealing when in contact with the cold gas or air returned to the compressor. On the other hand, such oil must also be able to stand compression temperatures of from 200° to 300° F., and at the high pressures that are reached. A well-refined straight mineral oil having a viscosity of about 40 seconds Saybolt at 210° F. and a congealing point of about −20° F. will generally answer the purpose.

33. Saponification Test.—The presence of animal or vegetable oils in a lubricant is detected as follows: Place about a pint of the oil into the small iron boiler or saucepan and add

1 to 2 ounces of caustic soda or concentrated lye; boil the mixture for ½ hour and then set it aside to cool. A tablespoonful of chloride of sodium (common salt) thrown into the mixture while cooling will hasten the process. When thoroughly cool, examine the mixture; if the surface is covered with soap, the oil contains animal or vegetable fats; otherwise it is pure mineral oil.

34. **Precipitation Test.**—The precipitation test is for the purpose of ascertaining if the oil contains paraffin, waxes, gums, etc. Place an ounce of each of the oils in a separate ½-pint bottle, pour 2 ounces of gasoline into each bottle on top of the oil, and shake the bottles until the oil is dissolved by the gasoline; then allow the mixtures to settle. If there is a considerable amount of precipitation or sediment in any of the bottles, it indicates that the oil in them has been treated to produce artificial viscosity and should be rejected.

35. **Test to Detect Sulphuric Acid in Mineral Oils.**—Heat a small portion of the oil to 300° F. in the metal cup and pan of sand and maintain that temperature for about 15 minutes; after cooling, if the sample is considerably darker in color than the original oil, it contains sulphuric acid and is unfit to use in cylinders or on hot bearings.

36. **Test for Corrosion.**—A practical test for corrosion is sometimes made by submerging a clean copper strip in the oil for 3 hours at a temperature of 212° F. Oil that will not corrode metal should produce no discoloration of the copper strip after the stated period of time.

37. **Conradson Test for Carbon Residue.**—The test applied to a lubricating oil for the determination of the percentage of carbon residue remaining after the oil has been subjected to a high temperature is known as the Conradson test, after its originator. This test is strictly a laboratory test and should be conducted with the utmost accuracy. Its results are of interest to the engineer, as they show whether a lubricant subjected to very high operating temperatures is liable to become decomposed and

form hard deposits of carbon that may clog the passages of the lubricating system and prevent the free operation of the valves.

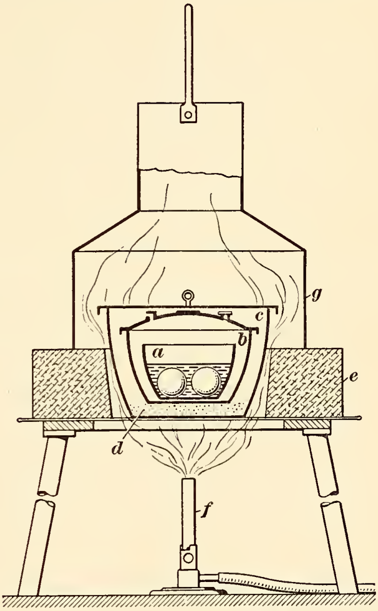


Fig. 1

The apparatus used in the Conradson test consists of a porcelain crucible *a,* Fig. 1, placed inside a covered iron crucible *b.* Both crucibles, in turn, are contained within a sheet-iron crucible *c* provided with a suitable cover. In the bottom of the crucible *c* is placed a layer *d* of dry sand, enough to bring the crucible *b* nearly to the top of the crucible *c.* The crucible *c* is mounted within an asbestos block *e* and is supported on a wire triangle under which a gas burner *f* is placed. A circular sheet-iron hood *g* provided with a chimney at the top surrounds the crucibles. The test is conducted as follows: Two glass balls about .1 inch in diameter are placed in the porcelain or silica crucible *a,* into which exactly 10 grams of the oil to be tested is poured. This oil should first be carefully freed from moisture or other suspended matter, as explained later. The combined weight of the crucible, glass balls, and oil sample is accurately determined, and then the crucible is placed in the center of the iron crucible *b.* Next, the sand is leveled in the large crucible *c* and the crucible *b* placed on the sand in the center of the crucible *c.* Covers are applied to both the crucibles *b* and *c,* provision being made to allow free exit to the vapors formed. The crucibles are then placed within the asbestos block *e* and surrounded by the hood *g*; next, heat from the gas burner *f* is applied underneath the crucible *c* for about 10 minutes. When smoke begins to appear above the chimney, the burner is tilted so that the gas flame plays on the sides of the crucible for the purpose of igniting the vapors. The burner flame should next be adjusted in such a way that the ignited vapors burn uniformly with the flame above the chimney. The period of burning the vapors is about 13 minutes. When the vapors cease to burn and no further blue smoke can be observed, the heat from the burner is again adjusted as at the beginning of the test so as to cause the bottom and lower part of the crucible *c* to become cherry red, this condition being maintained for exactly 7 minutes. The burner is then removed and the apparatus allowed to cool until no smoke appears. This cooling process should take about 15 minutes. The cover of the iron crucible *b* is removed, and the porcelain crucible *a* placed in a desiccator with the aid of heated tongs. After the crucible is thoroughly cool it is weighed, and this weight is subtracted from the original weight of the crucible, glass balls, and oil sample. From the result thus obtained, the percentage of carbon residue relative to the original sample can be calculated. The purpose of placing the glass balls in the crucible is to prevent the oil from being carried out of the crucible by the sudden formation of oil vapor by the applied heat.

Although the Conradson test is sometimes applied to Diesel fuel oils, it is of no great value as a means of measuring the residual content of fuel oil, because in this test oil is burned with an insufficiency of oxygen, whereas in a Diesel engine the oil is burned in the presence of an excess of oxygen.

38. Emulsification and Demulsibility Tests.—In order to determine the manner in which a lubricating oil will act in the presence of water, and also the rate at which the oil will separate from the emulsion so formed, lubricating oils are sometimes subjected to special tests, known as emulsification and demulsibility tests. The degree of emulsification of an oil depends on several factors, such as the viscosity of the oil, the manner of its refinement, the composition of the crude from which the oil is derived, and the nature of the service to which the lubricant is put. Oils that readily form emulsions with water are apt to form a sludge in the oil circulating pipes with harmful effect on efficient lubrication. If the demulsibility of the oil, or the rate at which the emulsion formed will separate out, is low, the oil must at times be withdrawn from the system and treated in a centrifugal separator to remove the water content. When mineral oils are mixed with water a certain amount of oxidation will occur under high temperatures in the presence of air and metallic particles, such as brass, copper, and iron. The extent of this oxidation affects the demulsibility of the oil, heavily oxidized oils demulsifying at a slower rate. In present practice accurate refining methods are relied upon to decrease the degree of oxidation that is likely to take place under the conditions named. Emulsification of the lubricant may occur through entrance of water into the circulating system through steam leaks, leaky packing glands or water seals, or leaky coils in the oil cooler, or from condensation of moisture in the air.

39. The apparatus for an emulsification test of lubricating oil consists of a 100 cubic centimeter graduated cylinder having an inside diameter of from $1\frac{1}{16}$ to $1\frac{1}{8}$ inches, and an oil or water bath for maintaining the contents of the cylinder at the specified temperature. The cylinder is immersed in this bath not lower than the 85 cubic centimeter mark, and the mixture of oil and water in the cylinder is subjected to violent agitation by a paddle mounted in the cylinder and revolving at 1,500 revolutions per minute. The mixture placed in the cylinder consists of 40 cubic centimeters of distilled water and a like amount of the oil to be tested, and is kept at a temperature of 130° F. by the heated surrounding bath. The stirring of the mixture is continued for 5 minutes, then the paddle is withdrawn and wiped clean, care being taken to return to the cylinder as much of the wiped off emulsion as possible. After the cylinder has been allowed to stand at 130° F. for a specified time, the mixture is inspected. Usually the test specifications prescribe that no continuous layer of emulsion shall remain.

In another emulsification test adopted by the American Society for Testing Materials, live steam is passed into a measured quantity of oil under controlled temperature conditions of from 190° to 195° F. for a specified time, generally from 4 to $6\frac{1}{2}$ minutes. The oil container is then transferred to a separating bath, the surrounding temperature being maintained within a range of from 200° to 203° F. Next, the volume of the oil layer separated from the condensed steam is observed at not less than 30-second intervals, until 20 cubic millimeters have separated out. The elapsed time in seconds from withdrawal of the steam delivery tube until the foregoing amount of separation has taken place is recorded as the *emulsification number* of the oil.

40. For the demulsibility test the apparatus used is the same as that used in the emulsification test. A mixture of 27 cubic centimeters of the oil to be tested and 53 cubic centimeters of distilled water is placed in the cylinder, then the cylinder is heated by the surrounding bath to a temperature of 130° F. The mixture is stirred for 5 minutes by the paddle revolving at a speed of 1,500 revolutions per minute. The paddle is then withdrawn and carefully wiped as before. Next, the cylinder is allowed to stand at a constant temperature of 130° F., readings being taken every minute of the position of the line of demarcation between the topmost layer of oil and the adjoining emulsion. The rate of settling out of the oil usually increases to a maximum and then decreases. The maximum value in cubic centimeters per hour is called the demulsibility and is recorded as the numerical result of the test. Each rate of settling is the average rate calculated from the time of stopping of the paddle rotation to the time of reading. For example, if 3 cubic centimeters of oil has settled out after the first 5 minutes since the paddle ceased to revolve, the rate of settling is recorded as $\frac{60}{5}\times 3$, or 12×3, or 36 cubic centimeters per hour. If, in 12 minutes after the paddle is stopped, 13 cubic centimeters of oil has settled out, the rate of settling will be $\frac{60}{12}\times 13$, or 5×13, or 65 cubic centimeters per hour. When the maximum rate of settling has not been reached at the end of 1 hour, the test is discontinued and the demulsibility taken as the number of cubic centimeters that settled out in the hour.

LUBRICATION SYSTEMS

GRAVITY SYSTEM

41. Description.—The simplest system of lubrication is that in which the oil is fed by gravity from a cup or other receptacle having a feeding device that permits the oil to be seen plainly as it is fed into an oil tube leading to the bearing or other surface to be lubricated. Gravity sight-feed lubricators, as the lubricating devices for this system are called, are often provided with needle-valve adjustment in order to be suitable to any rate of oil feed. In spite of its simplicity, the gravity-lubrication system is less desirable than other lubricating systems, for the reason that an economical and uniform feed cannot be maintained over long intervals of time. Variations in the oil temperature and in the oil level in the container cause a change in the rate of feed, and clogging of the opening of the needle valve of the oil cup by impurities that may be carried along may stop the feed altogether. Gravity sight-feed lubricators must be cleaned regularly if satisfactory results are to be attained. This method of lubricating the bearings of modern engines is therefore rarely applied. It is sometimes used to lubricate less important bearings and minor engine parts, such as levers, governor mechanism, and, in general, when the size of the installation does not warrant the expense of a more efficient system of lubrication. Constant attention is required to see that the oil cups are not allowed to become entirely empty, and that the required amount of feed to the bearings is maintained during the operation of the engine.

42. Wick-Feed Oil Boxes.—One form of wick-feed oiler used in connection with a gravity-feed lubrication system is shown in Fig. 2. Modern design of wick-feed oil cups specifies a wide and shallow cup, as shown in the illustration, rather than a deep cup. The end of the central tube *a* in the cup should extend above the normal oil level. The feed itself can be regulated by varying the number of strands of the wool wick *b*. The greater the number of strands in the wick, the greater the quantity of oil that will be fed. It has been found in practice that when the discharge end of the wick is about 2 inches below the oil level in the cup, the rate of flow will be about the maximum obtainable with a given number of wool strands. Decreasing the length of the wick cuts down the rate of flow. A change in the level of the oil in the cup will also affect the rate of flow to some extent; therefore, to obtain a fairly uniform flow the oil level in the cups should not be permitted to vary too much between fillings. As the flow of oil is not in plain sight, the oil level in the cups must be closely watched. Wick-feed oiling is only applied in small engines and then only to lubricate minor parts.

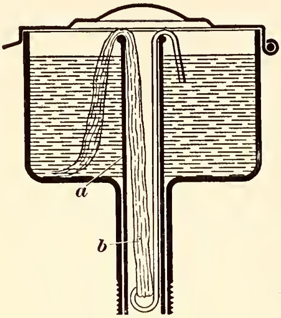


FIG. 2

43. Gravity multiple wick-feed oilers are classed as automatic lubricators. The oil boxes used are usually light brass boxes from which the oil is led through a number of brass oil pipes to the bearings, each bearing being supplied by a separate oil pipe provided with the necessary fittings. One form of multiple wick-feed oiler is shown in Fig. 3. It consists of a single reservoir *a* provided with a number of standpipes *b* that supply oil to the various engine parts. In some installations the stopcocks *c* in the standpipes are omitted, in which case the wicks *d* should be withdrawn from the standpipes when the engine is not running. The advantage of the stopcock attachment is that the

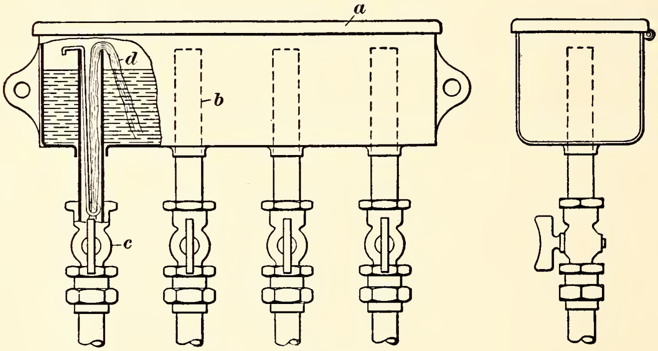


FIG. 3

wicks need not be withdrawn when the cocks are closed, and the space in the pipe above each cock is always filled with oil, thus enabling the operator to flood the bearings quickly, when starting the engine, by opening the cocks. In some cases the oil boxes are provided with sight-feed glasses, thereby enabling the engineer to observe the oil feed. Each box should have a sufficient capacity to last several hours without refilling.

44. To a certain extent the wicks also serve to filter and strain the oil on its way to the bearings. Cotton wicks should be avoided, as they are distinctly inferior to worsted yarn wicks. The latter are fitted with a lead sinker on one end and a twisted wire on the other end, by means of which the wicks are easily inserted in the tubes, and also easily withdrawn when it is desired to stop the oil feed. Dirt in the oil may cause the wicks to become gummy and may impair their usefulness. It is, therefore, good practice to *strip* each wick at regular intervals; that is, to withdraw the wick from its tube and squeeze it between the fingers in order to remove any dirt that may adhere to the wick. When the engine is being warmed up preparatory to starting, the engineer should give all bearings a liberal supply of oil from his hand oil can. During operation of the engine, hand oiling should also be resorted to occasionally to supplement the wick-feed oiling, and as a safeguard in case any of the wicks have stopped feeding.

SPLASH SYSTEM

45. Description.—In the splash system of lubrication oil contained in a sump in the lower part of the closed crankcase of the engine is splashed to the crankpin bearings by the end of the connecting-rod, which dips into the oil at each revolution of the crank. In this way lubrication of the bearings is maintained from the moment the engine starts until operation ceases. Some of the oil may be caught in suitable pockets on the inside of the crankcase and then led through pipes to the main bearings and eccentrics. In crosshead-type engines the splashing of the oil may also be used to lubricate the crosshead pin and the crosshead guides. The cylinders of single-acting engines may also be lubricated by the splash system but the disadvantage is that the amount of oil thrown depends largely on the speed of the engine and also on the oil level in the crankcase, which must be constantly maintained at a definite height. The use of this system of lubrication has been largely abandoned owing to the fact that the cylinders are usually either overlubricated or underlubricated, and that the oil spray in the hot crankcase becomes easily oxidized and forms a sludge. When the splash system is employed, there is very little or no control over the rate of oil feed, so that normally an excessive amount of oil is supplied to insure against lack of oil. Scraper rings and baffle plates are employed to prevent the flooding of the cylinder with oil. The increasing use of the high-speed engine caused the splash system to be abandoned. To keep the piston-pin bearings and the main bearings from pounding at high speeds, oil under pressure is introduced in the bearings to cushion the blows and also to prevent rupture of the oil film. Separate cylinder lubrication is secured in engines of this type by means of mechanical force-feed lubricators.

46. Oil Level With Splash System.—When charging the crankcase of an engine using the splash system of lubrication, care must be taken to see that the oil level is not raised too high. An excessive amount of oil in the crankcase results in a churning of the oil by the revolving crank. This agitation of the oil will prevent the settling of any impurities that the oil may contain, and in some cases causes the formation of sludge in the oil. As a general rule, a gauge is connected to the base of the crankcase, indicating how high the oil level should be carried and maintained. The height to which the oil should be carried is that which just permits the bottom end of the connecting-rod to dip into the oil about $\frac{1}{2}$ inch, and thus skim the surface without agitating the main body of the oil. Judgment and experience must be relied on in order to determine the correct oil level that should be carried in the crankcase. It should be noted in this connection that, when the engine is running, the oil level in the crankcase always drops, owing to the amount of oil splashed on the crankcase walls and suspended in the air.

If, from some source or other, water leaks into the crankcase of a splash-lubricated engine, care must be taken to remove it regularly and frequently, as otherwise the oil level will be unduly raised, thus causing excessive churning of the oil. This not only affects the proper distribution of the oil but also tends to increase its temperature somewhat. However, as the water evaporates, it draws the necessary latent heat from the oil, so that the temperature of the oil will rarely exceed 212° F. When the splash system of lubrication is used, it is very important to select the correct oil to suit the operating conditions, to keep the oil level at the proper height, to filter the oil frequently, and to remove all water regularly from the crankcase.

CONTINUOUS CIRCULATING SYSTEMS

47. Gravity-Feed Circulation System.—A continuous, or circulation, system of lubrication may be of either the pressure or the non-pressure type. In the non-pressure type, or gravity-feed system, the oil is led to the bearings from an elevated tank by gravity. Each feedpipe is fitted with an adjusting valve by means of which the flow of oil to each bearing is restricted to a small stream or to drops of oil, as observed through independent sight-feed glasses. The oil reaches the journals, therefore, with little or no pressure, depending on the height of the gravity tank above the point of delivery. From the main bearings the oil reaches the connecting-rod bearings by being run into an eccentric oil ring provided with each crank, from which it is carried by centrifugal force to the bearing. The piston pins are lubricated from a mechanical lubricator which also supplies lubricating oil to the cylinders.

A diagrammatic outline of a continuous gravity-feed lubrication system is shown in Fig. 4. The pump *a* draws the used oil from a sump in the engine base through the pipe *b* and discharges it to the top of an overhead storage tank *c*, which is mounted in a slightly inclined position. As most of the impurities in the oil find their way into the lowest part of the tank, the dirty oil is drawn off at that point through the pipe *d*. The oil flows through a sight overflow glass *e* placed so that the tank cannot be accidentally drained of oil. Thence the oil flows through a heater *f* into a centrifugal purifier *g* in which most of the impurities are removed and drained into the sewer through the pipe *h,* whereas the purified oil flows into a receiving tank *i.* A pump *j* then delivers the cleaned oil through the pipe *k* to the top of the overhead tank *c* at the end from which the clean oil is conducted by gravity to the engine bearings through the connection *l,* the cooler *m,* and the pipe *n.* In this way the system is made continuous, the oil being used over and over again.

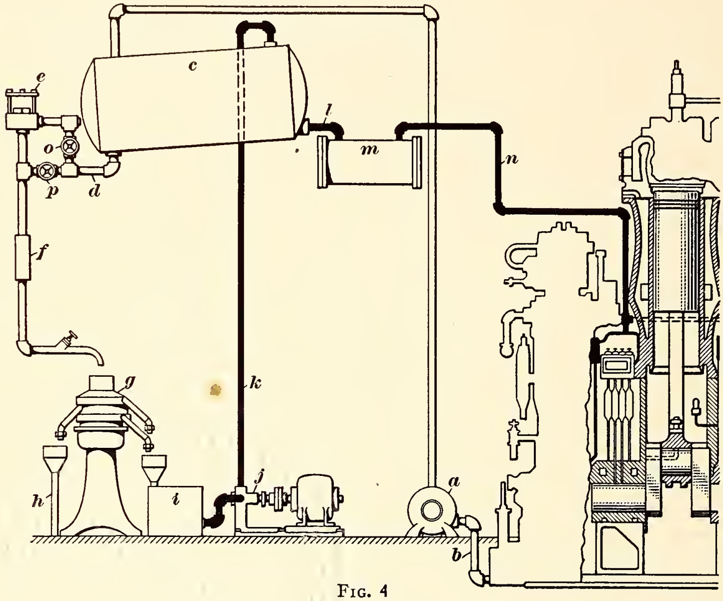


FIG. 4

Care must be taken to fasten the pipe connection *l* to the tank *c* at a point somewhat higher than the point from which the dirty oil is drawn from the tank at the opposite end. After the engine has been shut down, the purification of the oil may be continued for some time. In order to insure that all of the oil in the tank *c* is led to the purifier, the sight-glass *e* is by-passed by closing the valve *o* and opening the valve *p*.

48. Pressure-Feed Circulation System.—In the pressure system of lubrication, the oil is delivered from a reservoir in the engine base by a pump directly to the bearings. The quantity of oil forced to the bearings or other parts varies directly with the speed at which the engine is operated. To obtain a supply of oil proportional to the speed, the mechanism of the oil pump is actuated by some moving part of the engine, so that, the oil delivery pipes always being full of oil, lubrication is assured immediately on starting and cut off automatically on stopping. As some bearings require more oil than others, provision may be made for the regulation of the quantity of oil delivered to each bearing, sight-feeds being employed to enable the engineer to see at a glance whether or not the bearings are being properly lubricated. The oil is conveyed to the main bearings by pipes fitted in holes drilled in the bearings. Each crankpin is lubricated by oil forced through a hole drilled diagonally through the main shaft and the crank-cheek to the center of the crankpin. The pressure system may end here, or the oil may be conducted through a drilled hole in the connecting rod, or through a pipe attached to the outside of the rod, up to the piston pin or crosshead pin.

49. In Fig. 5 is shown a diagrammatic representation of a continuous pressure-feed circulation system. Used lubricating oil from the engine bearings is drained through a pipe *a* into a sump tank *b* provided with a strainer for removing from the oil all solid impurities. A rotary gear pump *c* draws the oil from the tank through the pipe *d* and discharges it through the heater *e* into a centrifugal purifier *f* in which all traces of water and other impurities are removed from the heated oil. The impurities are run off through a waste pipe *g*, and the cleaned oil is conducted through the pipe *h* back into the tank *b*. In most cases the carbon suspended in the oil is deposited in the bowl of the purifier, from which it is removed at regular intervals. A second rotary gear pump *i* draws the cleaned oil from the tank through the pipe *j* and discharges it through a cooler *k*, in which the temperature of the oil is reduced, to the engine bearings, thereby completing the cycle. In other systems the purified oil is drawn by the pump *i* from a receiving tank attached to the centrifugal purifier *f* and discharged directly into the cooler *k* on its way to the bearings, without first passing into the sump tank *b*, where it might become contaminated by the dirty oil from the bearings. The oil may be sent over and over again through the system, except that a certain amount of make-up oil must be furnished from a storage tank to take the place of that which is lost by leakage or through other causes. The pump *i* discharges the oil at a pressure of from 15 to 40 pounds per square inch into a manifold from which branch pipes lead to the various bearings.

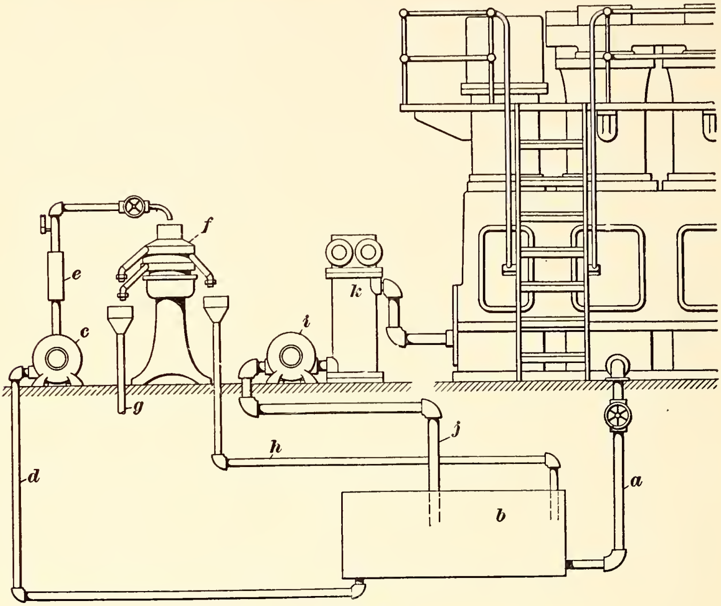


Fig. 5

50. The difference between a non-pressure and a pressure system of lubrication is that in the pressure circulation system the oil pump furnishes to the bearings an excessive amount of oil at all times during the operation of the engine. The oil, therefore, serves not only to lubricate the bearings but to carry off the heat generated in the bearings as well. During operation of an engine lubricated by the pressure system, all clearance spaces in the bearings are completely filled with oil under whatever pressure may be maintained in the system. This insures that the necessary separating film of oil between the surfaces of the bearings and the journals is formed and maintained.

51. Dry Sump.—Although in many engines the used oil from the bearings drains to a compartment at the bottom of the crankcase, it has been found to be better practice to drain the oil into a separate sump placed below the crankcase, and known as a dry sump. All oil that collects in the crankcase flows to the dry sump by gravity, so that no oil is stored in the crankcase at any time. The purpose of this arrangement is to have only a minimum quantity of oil in the crankcase exposed to the high engine temperatures, so that there will be little chance of the oil becoming vaporized, thereby setting up an undesirable pressure in the crankcase. A typical dry sump is shown at *b* in Fig. 5.

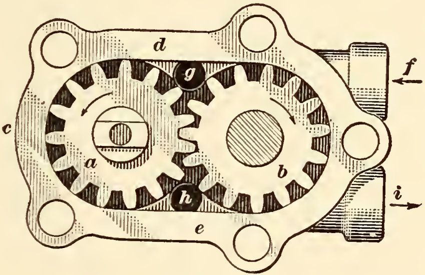


Fig. 6

52. Oil Circulating Pump.—Various types of oil pumps for circulating the oil through a pressure lubricating system are on the market, but the type most generally used is known as the rotary gear pump. The gear pump occupies, relatively, but little space for its capacity and is light, simple, inexpensive and highly efficient. The main advantage of this type of pump over the reciprocating type is that the gear pump delivers oil to the bearings at a very steady pressure without the use of an air chamber. One common form of gear pump is shown in Fig. 6. There are two meshing spur gears *a* and *b* on shafts having bearings in the housing *c*; the gear *a* is driven in the direction of the arrow marked on it and drives the gear *b*. The housing *c* closely fits one-half the circumference of each gear, and in conjunction with the two gears forms an inlet chamber at *d* and an outlet chamber at *e*. The inlet to the pump is at *f* and communicates through a port *g* with the inlet chamber; the port *h* in the outlet chamber communicates with the outlet *i*, from which a pipe leads the liquid to its destination. As the wheels revolve, each tooth acts as a piston that pushes a certain quantity of liquid ahead of it, thus taking it from the inlet chamber and carrying it around the semicircular parts of the housing to the outlet chamber. Gear pumps are also made with impellers having herringbone gear teeth, and, in this form, may be used to operate at considerably higher speeds than those of the simple gear pump. These pumps are generally driven directly from the engine crankshaft.

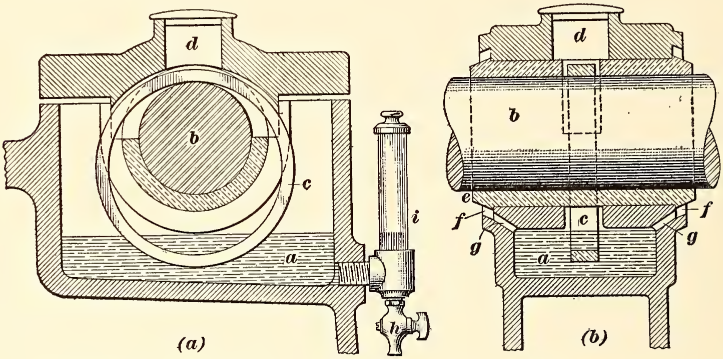


Fig. 7

53. Bath Lubrication and Ring Oiling.—Other lubricating systems than the gravity system and the circulation system, such as bath lubrication and ring oiling, are sometimes used to lubricate bearings other than main bearings. In the bath system of lubrication the bearings are wholly, or at least partly, immersed in oil. To attain this, each bearing is enclosed in an oil-tight reservoir. This method of lubrication is frequently applied to thrust bearings, the oil being carried from the reservoir underneath the bearing to the contact surfaces by revolving collars on the shaft. A bearing of the ring-oiled type is illustrated in Fig. 7, view (*a*) showing a section at right angles to the shaft, and view (*b*) a conventional longitudinal section. The oil is contained in a reservoir *a,* and is carried to the crankshaft journal *b* by the ring *c,* which rests on the journal and revolves slowly as the shaft revolves. Oil is supplied to the reservoir through the cup *d.* After leaving the surface of the journal, the oil flows down the end surface of the bushing *e* into the circular grooves *f,* and through the ports *g* back into the reservoir *a.* When the oil becomes unfit for further use, the reservoir is drained through the cock *h.* A glass gauge *i* indicates the amount of oil contained in the oil chamber. This type of bearing is also known as a *self-oiling bearing.* To operate efficiently, the inside surface of the ring must have a smooth finish and be truly circular, as otherwise the ring may fail to rotate evenly and in extreme cases may fail to rotate at all. Whenever the oil is changed, the reservoir should be thoroughly cleaned. Ring oiling may be applied in some cases to the bearings of auxiliary machinery. Care must be taken to inspect ring-oiled bearings regularly to ascertain whether the rings are revolving properly with the journals.

54. **Hand Oiling.**—Light running gear of engines is often lubricated by the use of the hand squirt oil can. Even under the most favorable conditions hand oiling is more or less wasteful and should be resorted to only where better and more efficient methods cannot well be used. Hand oiling usually causes an excess supply of oil at the time of application; however, in many cases the parts will be badly in need of lubricant before the next periodic oiling. The most suitable oil used for hand oiling is a compounded oil, having a heavy body, that will not quickly run out of the bearing as would an oil of lighter body. The possibility that the oil may become thinned because of temperature conditions in the engine room must be given serious consideration, as in tropical climates, for instance, engine-room temperatures may be from 90° to 120° F.

MISCELLANEOUS LUBRICATING DEVICES

55. **Automatic Mechanical Lubricators.**—The cylinders and pistons of most types of engines are generally lubricated by automatic mechanical lubricators. Such devices provide forced,

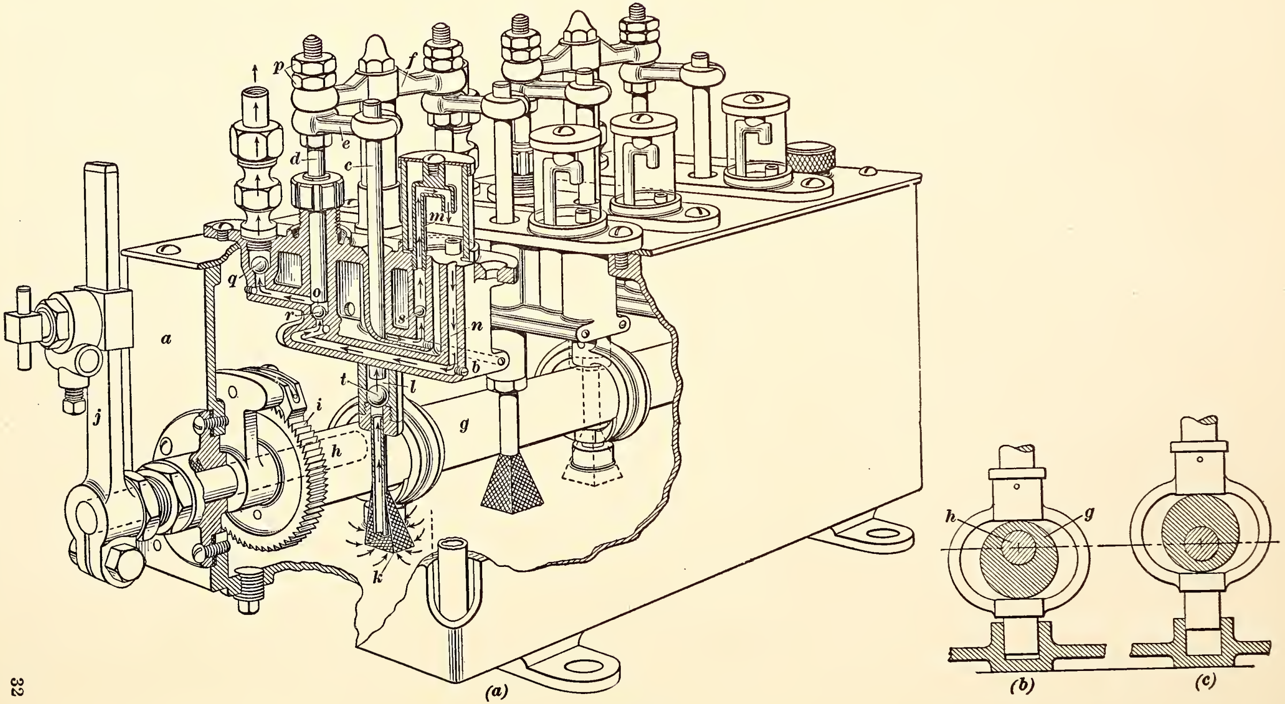


Fig. 8

or positive, feed lubrication and are operated from some moving part of the engine. One form of mechanical lubricator equipped with sight-feed is shown in Fig. 8 (*a*). It consists of an oil reservoir *a* in which several pump units are mounted. Each of these units serves a particular feed line leading to a part of the engine to be lubricated. The body *b* of each pump unit is hung from the top of the reservoir and contains two plungers *c* and *d*, connected at the top by a cross-piece *e* and actuated by another cross-piece *f*. In turn this cross-piece *f* is moved up and down by an eccentric mechanism consisting of a cylinder *g* mounted

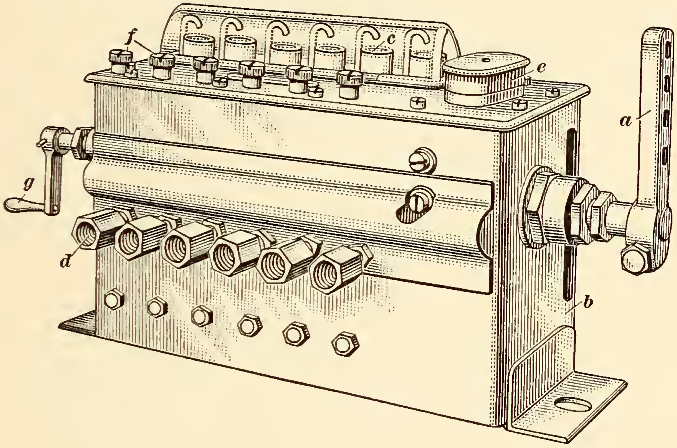


Fig. 9

eccentrically on the shaft *h*. The two extreme positions are shown in views (*b*) and (*c*). The shaft *h*, view (*a*), is revolved by a ratchet mechanism *i*, operated by the lever *j*, which derives its oscillating motion from any reciprocating part of the engine, such as the crosshead or valve gear. On the upward stroke of the suction plunger *c* oil is drawn from the reservoir *a* through the strainer *k* into the chamber *l*, and on the downward stroke of the plunger *c* the oil is forced into the sight-feed *m*. During the upward stroke of the delivery plunger *d* the oil is drawn from the sight-feed *m* through the passage *n* into the chamber *o*, whence it is forced to the feed line by the downward stroke of the plunger *d*. The amount of oil delivered per stroke depends on the length of the stroke of the delivery plunger *d*, which can be regulated by means of the adjusting nuts *p* on the delivery plunger. Tightening the nuts results in a decreased amount of lost motion of the cross-piece *f*, and consequently increases the length of stroke of the delivery plunger and the quantity of oil delivered, and vice versa. The ball check-valves *q*, *r*, *s*, and *t* prevent the return of the oil on its passage through the lubricator.

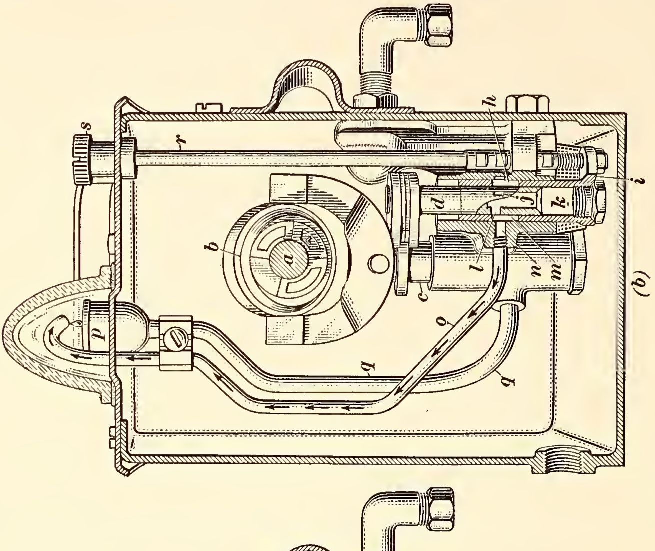


Fig. 10

56. Valveless Mechanical Lubricator.—A very efficient valveless mechanical lubricator is shown in Fig. 9. The device is built for any number of oil feeds up to and including 32, and may be operated from some moving part of the engine by a ratchet, as shown at *a,* or by a rotary drive, such as through gearing or by a small electric motor through a suitable speed reduction unit. The lubricator mechanism consists of a number

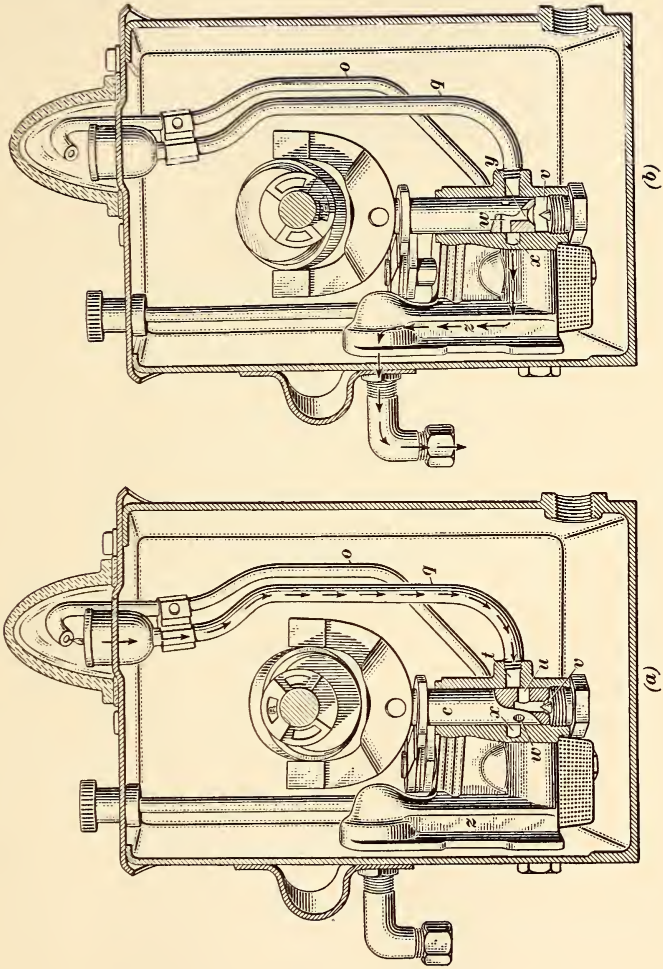


Fig. 11

of individual oil pumps, each connected to a separate oil feed and all mounted in a tank *b* containing the lubricant. The arrangement is such that there is one impulse from each pump for each revolution of the drive shaft. Each of the oil-feed lines is provided with a sight-feed *c* indicating the amount of oil being fed to each oil lead. The oil outlets are shown at *d* and the filling cap is shown at *e*. The adjusting buttons *f* are used to regulate the oil feed in each of the delivery leads. The lubricator may be operated by hand, after the ratchet has been disconnected, by turning the crank *g*.

The operation of the lubricator is explained with the aid of the four cut-away views of one of the oil pumps, shown in Figs. 10 and 11. On the driveshaft *a*, Fig. 10 (*a*), are mounted a number of eccentric disks *b*, one for each pump, that by virtue of their angular mounting impart a reciprocating as well as a turning movement to the delivery plunger *c*. These movements of the delivery plunger are communicated to the metering plunger *d*, the mechanical connection between the two plungers being such that the movements of both plungers are identical. The eccentric disk is mounted on the driveshaft at an angle of 27°, hence one complete revolution of the eccentric, as indicated in Fig. 12 by a change from the solid position *a* to the dotted position *b*, causes not only a vertical movement of both plungers of about $\frac{7}{32}$ inch, but a rotating movement through 54° as well.

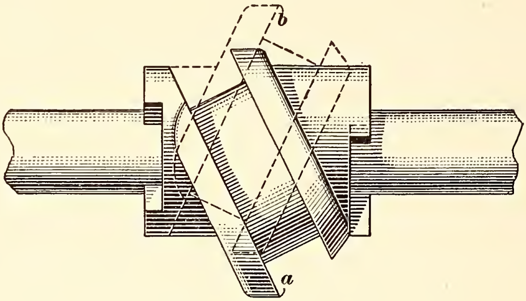


FIG. 12

57. In Fig. 10 (*a*), the metering plunger *d* is shown at the beginning of the upward, or suction, stroke. During this stroke oil is drawn through a strainer *e* and a drilled passage in the barrel *f* into the suction port *g,* and thence through the port *h* in the sleeve *i* and the passage *j* in the plunger *d* into the chamber *k*. It will be noted that during the suction stroke the port *h* registers with the passage *j* in the plunger, but the passage *l* in the plunger does not register with the discharge port *m,* so that no oil can escape from the pump cylinder.

In view (*b*) the plunger *d* is shown beginning its downward, or discharge, stroke. The mounting of the eccentric *b* has caused the plunger to turn a sufficient amount to prevent the port *h* from registering with the passage *j* during the downward stroke of the plunger. The passage *l* in the plunger is now registered with the discharge port *m* and the oil will be forced through the port *n* into the tube *o,* whence it passes through the sight-feed cup *p* and the tube *q* to the suction side of the delivery plunger *c*. The number of drops of oil forced into the sight-feed tube *o* is controlled by the position of the sleeve *i,* which may be regulated through the spindle *r* and adjusting button *s*. With the sleeve in its lowest position, all the oil contained in the chamber *k* is discharged into the tube *o,* but when the sleeve is raised a certain amount, the passage *l* in the plunger *d* registers with the port *m* for a shorter duration of time than before, so that less than the maximum amount of oil is discharged, the remainder being returned to the tank through suitable by-pass ports. In this way the quantity of oil forced into the tube *o* is metered. The adjusting buttons *s,* shown at *f* in Fig. 9, therefore furnish a convenient means of varying the amount of oil delivered to each oil lead as desired.

58. The delivery plunger is shown at the start of the upward, or suction, stroke in Fig. 11 (*a*). Oil from the receiving tube *q* enters the pump cylinder through the port *t* and flows through the registering passage *u* in the plunger *c* into the chamber *v*. The discharge passage *w* in the plunger does not register with the port *x* during the suction stroke, so that the oil remains confined in the chamber *v*. At the end of the upward stroke and at the beginning of the downward, or delivery, stroke the plunger is rotated through 54°, as explained before, causing the suction port *t* to cease registering with the passage *u*. During the downward stroke of the plunger the passage *w*, view (*b*), in the plunger registers with the delivery port *x*, so that the oil is forced out of the chamber *v* for final delivery through the passages *y*, *w*, *x*, and the channel *z*.

59. Grease Cups.—Grease cups are made in various ways and either as plain or compression cups. In a plain cup the grease flows down only by gravity as the heat of the bearing melts it; to assist the grease, it is a good practice to put a piece of small copper wire in the hole through which the grease leaves the cup. A compression grease cup may be hand-operated or spring-operated; Fig. 13 shows one of the type first named. By screwing the cap down by hand over the base, the grease is forced to the part requiring lubrication.

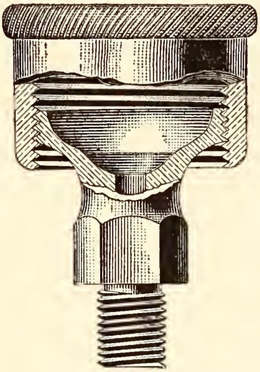


Fig. 13

Spring-operated compression grease cups have a piston, on top of which is placed a spring that continually forces the grease to the bearing. In most of them the rate of flow can be regulated by a suitable valve.

CARE OF LUBRICANTS

OIL-CONDITIONING METHODS

60. Storage and Handling of Lubricants.—The proper storage and handling of lubricants is a matter of considerable importance. Filling pipes, strainers, tanks, and containers should be so arranged and marked as to avoid any possibility of mixing or contaminating the lubricants, and to prevent the use of the wrong lubricant for a given purpose. Separate tanks for the various oils, each tank plainly marked with the name of the oil contained therein, are essential. This applies in particular to so-called cold-test lubricants used for the internal lubrication of ice machines; they should be kept in separate, marked containers to distinguish them from oils used for the lubrication of bearings. Care should be taken not to use any filling vessel for more than one kind of oil. The various tanks and containers should be periodically emptied and thoroughly cleaned, after which they should be refilled with pure oil, the interval between the cleaning operations to be determined by the prevailing conditions in any given case. Carelessness in the storing and handling of lubricants, and in their application by methods that permit contamination by dirt, grit, or water, are frequently responsible for bearing troubles.

61. Recovery and Purification of Oils.—The quality of high-grade lubricating oils is, as a general rule, not seriously impaired by the process of lubricating the various engine parts. This fact has been demonstrated by the continuous use of high-grade oil in engines equipped with a circulation system of lubrication. In such systems the only loss of lubricant is that incurred by leakage, which must be compensated for by providing from time to time a small supply of so-called make-up oil. However, it is not possible to prevent impurities from contaminating the lubricating oil. Such impurities may result from atmospheric dust entering with the air, leakage water from the jackets, worn gears and bearings, carbon formation in the cylinders, etc, and after a certain length of time may cause the lubricating oil to fail to function properly. The fact that oils may be recovered and conditioned for reuse has resulted in added oil economy in many plants.

When it is desired to recover and purify bearing oils, means should be provided for collecting the used oil in as clean a condition as possible. To accomplish this, the engine bed should be fitted with pans to catch the oil dropping from the cranks and main bearings. These pans should be fitted with drain pipes leading to a sump tank in which the heavier particles of dirt may settle to the bottom, together with any water that may be present in the oil. From the sump tank the oil is pumped to a filter in which the impurities remaining in the oil are removed. Many different types of oil filters are in use. In case the lubricant is not a pure mineral oil but a compounded oil, the oil will form with leakage water from the jackets an emulsion that cannot be removed easily by the settling method just described.

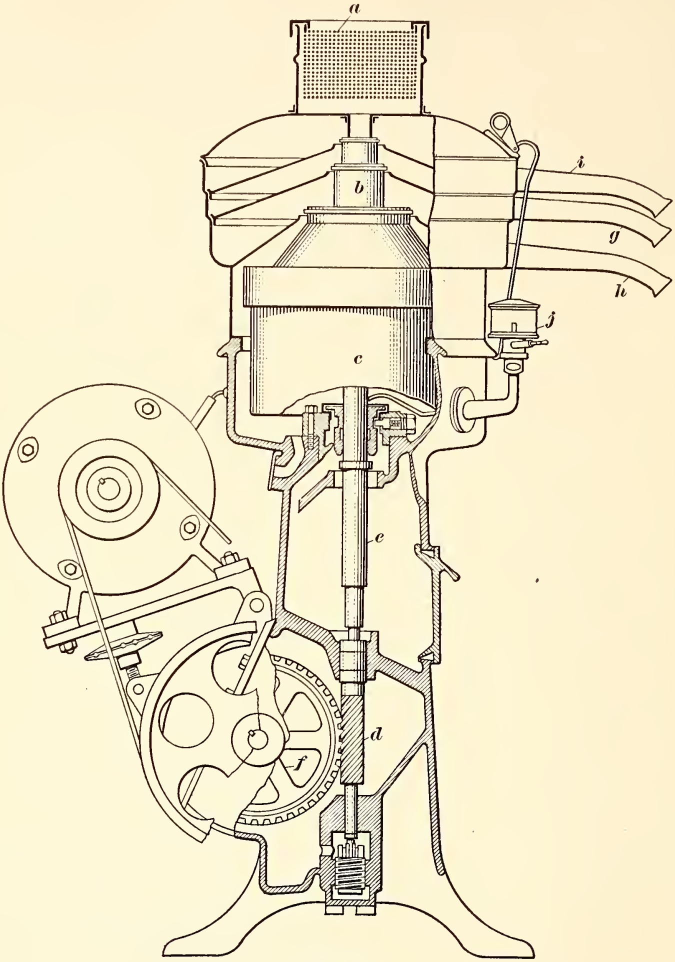
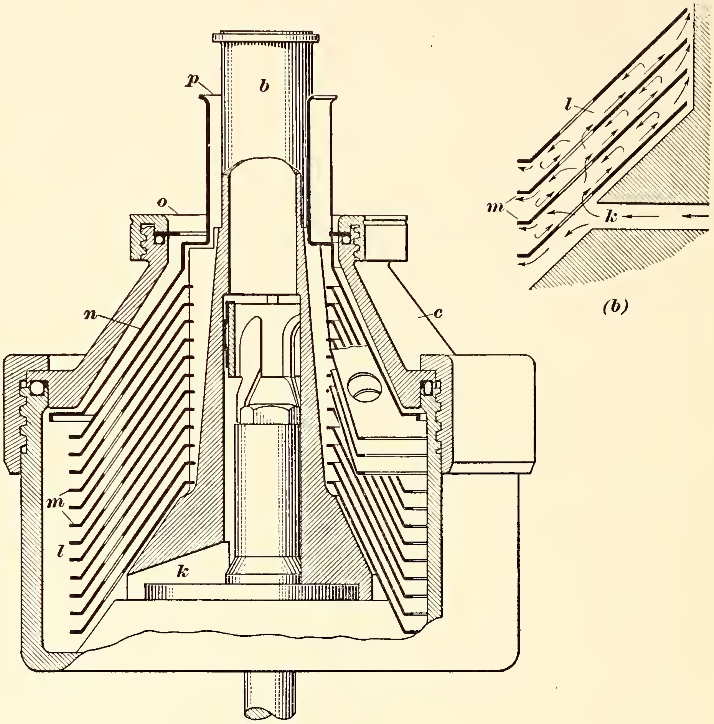


Fig. 14

62. Centrifugal Oil Purifiers.—A more efficient method of purifying oil than that described in the preceding article consists in cleaning the oil in a centrifugal purifier. Several forms of such purifiers are on the market. In all of them centrifugal force is used to remove the impurities from the oil. In Fig. 14 is shown a part sectional view of one form of centrifugal oil purifier. The impure oil enters the purifier through the strainer *a* mounted on top of the center tube *b*. The tube and the bowl *c* are given a very fast rotating motion by means of a worm *d* on the vertical shaft *e*, meshing with a power-driven wormwheel *f*. On its way downwards in the tube *b*, the oil receives a rotary motion from contact with the tube, and, at the bottom of the tube, passes outwards into the bowl *c*, in which the actual separation of the oil from its impurities takes place. The purified oil is finally carried off through a spout *g*. Another spout *h* carries off the water and impurities, while a third spout *i* at the top serves to carry off the overflow in case the oil should be fed into the purifier at too fast a rate. The solid impurities are deposited in the bowl and are removed at regular intervals. It is possible to control the process in such a way that the solids will be carried off through the spout *h* with the water, but this is not generally done, as in this case some of the oil may escape with the water owing to the difficulty of separation.

The worm and wormwheel that produce the rotating motion of the purifier bowl run in a bath of oil provided by means of an oil cup *j* that also furnishes oil to the bearings of the vertical shaft *e*. The weight of the bowl *c* and spindle *e* is taken by a suitable thrust bearing in the lower end.

63. A sectional view of the purifier bowl *c*, Fig. 14, is shown in Fig. 15 (*a*). This bowl revolves about a vertical axis at a very high speed, thereby causing the liquid contents of the bowl to be thrown outwards by centrifugal force. In so doing, the water and impurities are separated from the oil. The heavier impurities are deposited near the outer wall of the bowl, whereas the lighter ones are deposited more toward the center, the result being a very effective purification of the oil. The oil first receives a rotary motion in its downward passage through the tube *b* and then passes outwards through the lower passage *k* into the main chamber *l* in which the separation takes place. The chamber *l* contains a number of cone-shaped disks *m* that assist in the separation process. The distance between two adjoining disks is only a few thousandths of an inch, the oil being distributed between the disks through a number of holes in them. The heavier particles in the impurities and water entrained with the oil are driven outwards and gather near the outer wall of the bowl, eventually passing outside of the cone-shaped partition *n* and overflowing at *o*. The lighter purified oil passes inwards between the disks *m* and within the inner face of the partition *n*, finally leaving through the passage *p*, being carried off through the spout *g*, Fig. 14. The manner in which the cone-shaped disks *m*, Fig. 15 (*a*), assist in separating the impurities from the oil is shown in detail in view (*b*). Under the influence of the centrifugal force the impurities in the oil, on



(*a*) (*b*)

Fig. 15

entering the chamber *l* from the passage *k*, are thrown against the lower face of each of the disks *m*, whereas the purified oil is thrown against the upper face, so that the stream of oil and the impurities will move in opposite directions, as indicated by the arrows, with a minimum amount of interference.

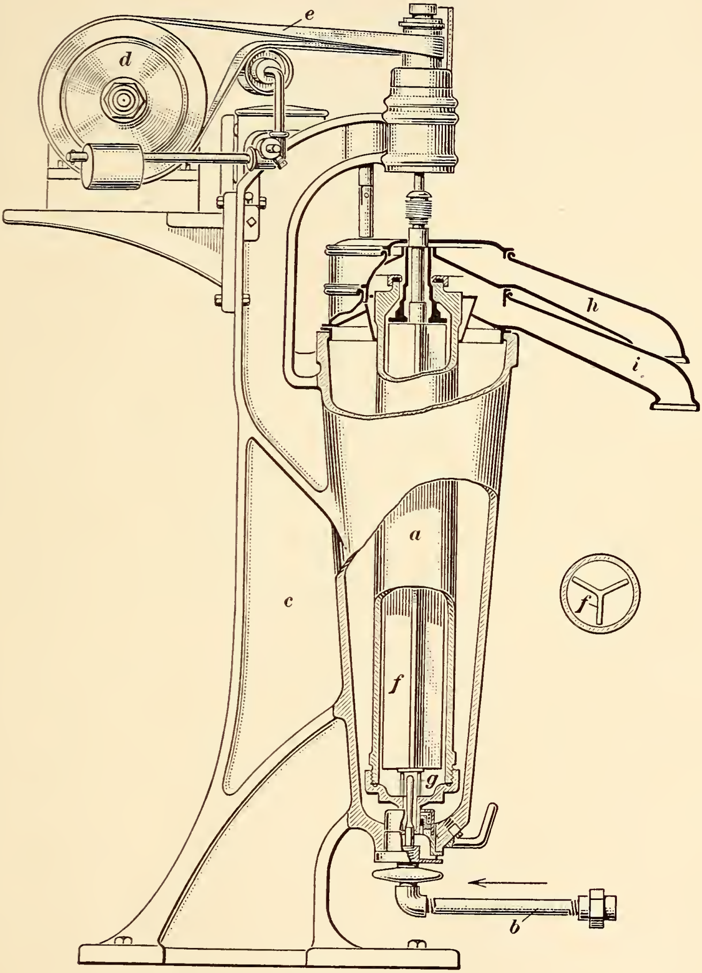


Fig. 16

64. Another form of centrifugal oil purifier is shown in Fig. 16. The oil is admitted to the bottom of a long cylindrical bowl *a* through a pipe *b*. The bowl *a* is supported in bearings carried in a frame *c* and can be revolved at very high speed by an electric motor *d* through a belt *e* and a flexible spindle. Inside the bowl, and rotating with it at the same speed, is fitted a three-wing dasher *f* resting on a bearing *g*. The oil in the bowl acquires a rotating motion by the friction caused by contact with the walls, the speed of rotation being gradually increased by the action of the dasher. Under the action of centrifugal force the oil is forced against the inner wall of the bowl, causing the entrained impurities to be deposited on the wall owing to the difference in specific gravity of the oil and the impurities. Any water contained in the oil will be separated out and form a layer between the oil and the wall of the bowl. The cleaned oil and the water ultimately leave the bowl at the top through separate openings and are discharged through the pipes *h* and *i*, respectively. At regular intervals the rotation of the bowl is stopped to allow it to be removed and cleaned. The speed at which the bowl is revolved is about 15,000 revolutions per minute. To prevent the harmful gases given off by the fuel oil from escaping into the room the entire bowl of the apparatus is usually enclosed within a gas-tight casing.

65. The type of centrifugal purifier here described is also made as a complete and self-contained oil-purifying unit, being combined with two direct-driven gear pumps, one to feed dirty oil to the purifier, and the other to carry the purified oil back to the system.

The unit is also provided with a heater, and the necessary controls. The heater may be supplied with heat from the engine exhaust, or it may be built in the form of an independent electric heater. The object of the heater is to heat the dirty oil to about 160° F., at which temperature purification is most effective. Electric control is provided to prevent the heater from being turned on when the pumps are not operating.

66. Batch System and Continuous System of Oil Purification.—In applying the centrifugal oil purifier to the various oiling systems used in modern engine practice, two general methods of cleaning the oil are used. In the first method, a portion of the oil is removed from circulation each day, or at stated periods, and is run through the purifier, then is returned to the circulation system. During the period when this batch of oil is being purified, the remaining oil in the system is constantly getting into a poorer condition, until it is restored to a certain degree of purity by the addition of the batch of oil that has just been purified. This method is known as the batch system of oil purification.

In the second method, known as the continuous system of purification, a portion of the oil is constantly withdrawn from the circulation system and passed through the purifier, after which it is returned to the system. As a rule, the oil is drawn from the pipes immediately after it has passed through the strainers and while it is still warm from use in the system, the heated condition of the oil being favorable to the purification process. An oil pump is used to return the purified oil to the lubricating system, but first it is passed through a cooler to reduce the temperature before the oil is applied to the bearings. The continuous system of purification maintains the lubricant at all times in the cleanest possible conditions.

67. Several commercial devices are in use in which used oil from the crankcases of internal-combustion engines may be reconditioned. In the Miller oil purifier not only are dirt, carbon, gasoline, and water removed from the used oil, but the products of any oxidation that has taken place in the oil, with consequent increase in acidity, are effectively neutralized as well. The used oil is first pumped into the purifier direct from storage tanks, no settling being required. A float switch automatically stops the pump when the proper quantity of oil has been pumped into the container. The proper quantity of a patented clay composition, known as Millene, is then added to the batch through an opening at the top of the container to act as neutralizing agent, then the batch is heated by means of an electric heater. During the heating process the oil is thoroughly agitated by a fan or paddle, rotated by a small electric motor. The oil is heated to a temperature at which all of the volatile impurities are removed, at which time a thermostat automatically cuts out the electric heater and lights a lamp to warn the operator that the batch is ready to be filtered. A motor-driven pump then forces the oil through a filter press, thereby removing all solid materials present in the oil, including the clay used as neutralizing agent. It is claimed that the oil reclaimed in this manner has the same lubricating value as the original pure oil. The volatile constituents that are driven off during the purification process are passed through a condenser and yield a penetrating oil of good quality. The entire apparatus, including the condenser, heater, filter, and pumps, is self-contained.

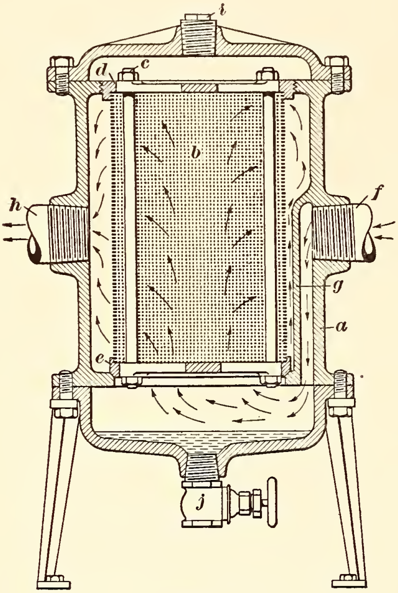


Fig. 17

OIL FILTERS

68. Types of Oil Filters.—Several forms of oil filters are used in connection with continuous oiling systems. A common form of filter employs a metal strainer, usually in the shape of a basket, that forms a receptacle for the foreign matter in the oil. Filters of this type are able to remove the coarser particles only. Other types of filters use as filtering medium cloth bags made of felt, flannel, or wool, through which the oil is forced by pressure of a pump. Oil filters are frequently of the duplex type, so that the oil flow may be shifted from one filter to the other. The one previously in use can then be readily removed for cleaning without interfering with the operation of the system.

69. Construction of Strainers.—Strainers are usually made of either wire mesh or perforated sheet metal; they should be fitted so that they can be easily removed for cleaning when they become clogged. A pressure gauge connected by a three-way valve to each side of the strainer will serve to warn the operator when the strainer is in need of cleaning. The reason for this is that as the strainer becomes clogged, the oil pressure at the outlet side of the filter is reduced on account of the difficulty of forcing the oil through the meshes. The area of the openings in the strainer should be several times the cross-sectional area of the pipe in order to prevent the oil pressure from being unduly decreased. One form of single oil strainer is shown in Fig. 17. It consists of a cast-iron body *a* containing a finely perforated brass strainer *b* secured by tie-rods *c* between the brass spiders *d* and *e*. The oil to be cleaned enters at *f* and is deflected to the bottom of the body *a* by the baffle wall *g*. It is then forced through the openings in the strainer *b* and out through the out-

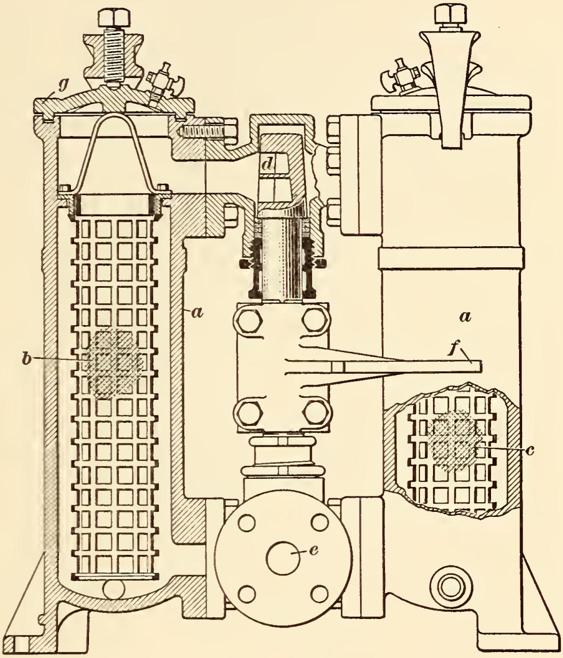


Fig. 18

let *h*, as shown by the arrows. The strainer can be cleaned by blowing steam through the blow-out connection *i*. Any water collected in the bottom of the body *a* can be drained off by opening the valve *j*.

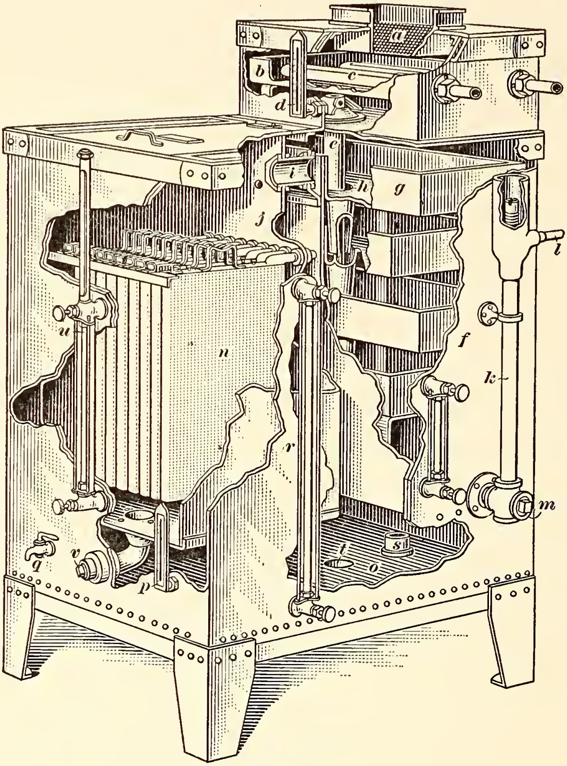


Fig. 19

70. Duplex Oil Strainer.—A sectional view of a duplex oil strainer is shown in Fig. 18. It consists of a cast-iron body *a* fitted with perforated tinned-iron baskets *b* and *c* mounted in separate compartments for straining the oil. In operation the oil enters through the inlet *d* and is discharged through the outlet *e*, after being strained through either one of the baskets *b* and *c*. This may be accomplished by moving the lever *f* either to the left or to the right; for example, moving it to the right sends the oil through the basket *b* and cuts out the basket *c*, so that the latter may be removed for cleaning purposes. The baskets are suspended inside the strainer body and may be lifted out after the covers *g* have been removed. The strainer is connected to the oil piping in such a way that the entire device may

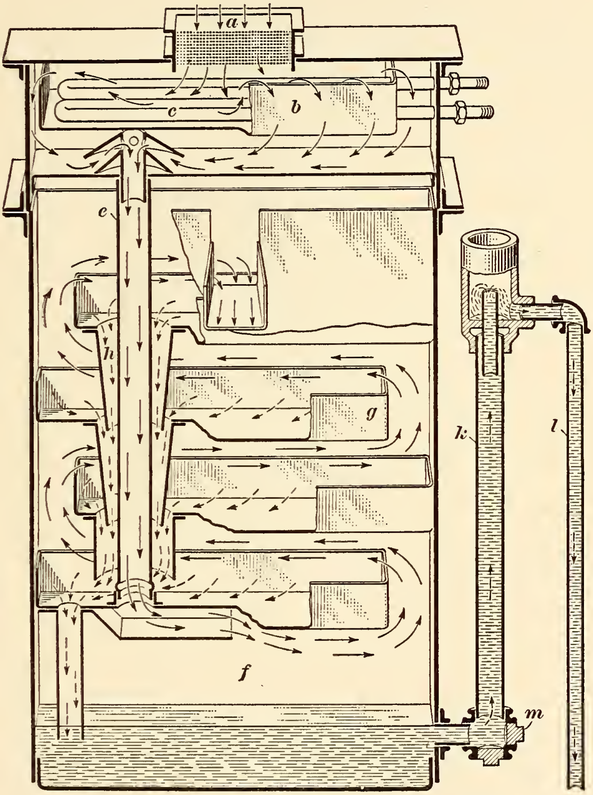


Fig. 20

be by-passed if necessary. In this case the by-pass is provided with a relief valve so adjusted that it automatically opens when a fixed maximum pressure difference exists between the suction and discharge sides of the strainer, caused by clogging of the strainer baskets. Thus, the flow of oil is not interrupted, but an alarm must be installed to indicate when the relief valve operates; otherwise the clogged strainer will go unnoticed unless discovered by the attendant. Strainers of this type are used to remove impurities from fuel oil as well as from lubricating oil.

71. Filter for Large Engine Installations.—The filter shown in Fig. 19 is used with large engines. The oil to be purified enters the filter at the top and passes through a strainer *a* and a heating pan *b* fitted with a steam coil *c*, the temperature being indicated on a thermometer *d*. The heated oil then drops through the pipe *e* and is deflected by a baffle at the lower end of the pipe, then travels upwards in the compartment *f* in a zigzag course under and over the trays *g*. As the oil travel is comparatively slow, ample time is afforded the water and solids in the oil to settle out into the trays. The water from each tray is conducted to the bottom of the compartment *f* through the sleeves *h* around the pipe *e*, thereby avoiding contact of the water with the rising oil. The path of the oil is shown by arrows in Fig. 20. The cleaned oil leaves the compartment *f*, Fig. 19, through the outlet *i* and enters the filter chamber *j*. The trays *g* are withdrawn at regular intervals for cleaning purposes. As the water accumulates in the compartment *f* it rises through the pipe *k* and finally overflows into the discharge pipe *l*, thereby maintaining the proper water level in the compartment *f*. This level is at the connection of the overflow pipe *l* to the riser pipe *k*.

72. The pipe *k*, Fig. 19, is provided with a cleanout *m*. The filter chamber *j* contains a number of filter bags *n* that remove any impurities that may remain in the oil. The filter units are held in place by spring clips and may be removed for cleaning without interrupting the operation of the filter. The filtered oil is collected in the chamber *o* equipped with a thermometer *p*, a draw-off cock *q* for sampling the oil, an oil gauge *r*, a 2-inch outlet opening *s* that may be connected to the suction of a circulating pump, and a drain *t*. The frequency of cleaning the trays and filter bags depends on the attending conditions of operation in any given case. A so-called oil and head gauge *u* is provided to indicate to the operator when the filter bags should be cleaned. A cleanout for the filter chamber is provided at *v*.

73. Edge Filters.—The oil filter shown in Fig. 21 (*a*) and (*b*) is known as an edge filter and comprises a large number of thin metal perforated disks *a* stacked on top of each other. The disks are separated by metallic spacers *b*, view (*b*), the thickness of the spacer determining the fineness of filtration. The oil to be filtered enters the filter through the inlet *c*, view (*a*). It then passes through the very fine spaces between the edges of the disks, rises through the slots in the disks, and passes out through the outlet *d*. The path of the oil through the filter is shown by arrows in the illustration. The disks *a*, view (*b*), and spacers *b* are assembled on a central shaft *e* that extends through the top casting *f*, view (*a*), of the filter. On the outer end of this shaft is a handle *g* by means of which the disk stack, or cartridge, can be rotated. When the stack is being assembled, a cleaning blade, or scraper, *h*, view (*b*), is placed between each two disks, extending outwards and mounted on a separate stationary post *i*. The disk stack is then drawn tightly together by a nut on the threaded portion of the shaft *e* and then locked in place. The scrapers extend across the rims of the disks *a* and

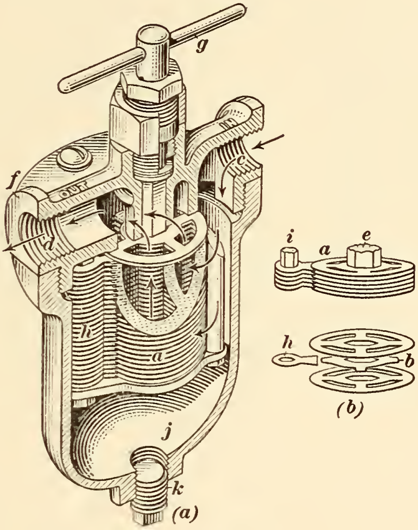
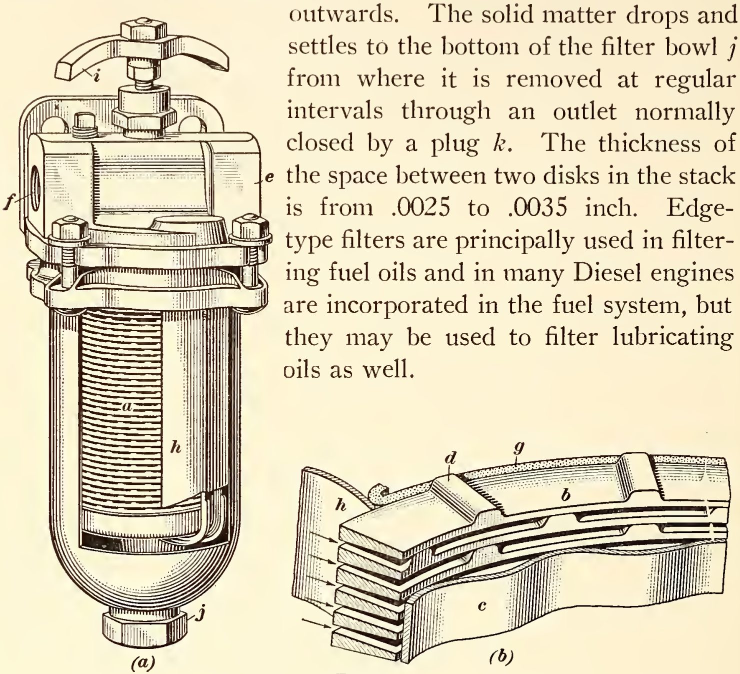


Fig. 21

are so shaped that, when the disk stack is revolved through one revolution by means of the handle *g,* view (*a*), any dirt particles lodged between the disks, or in the slots in the disks, are pushed outwards. The solid matter drops and settles to the bottom of the filter bowl *j* from where it is removed at regular intervals through an outlet normally closed by a plug *k.* The thickness of the space between two disks in the stack is from .0025 to .0035 inch. Edge-type filters are principally used in filtering fuel oils and in many Diesel engines are incorporated in the fuel system, but they may be used to filter lubricating oils as well.



(a) (b)

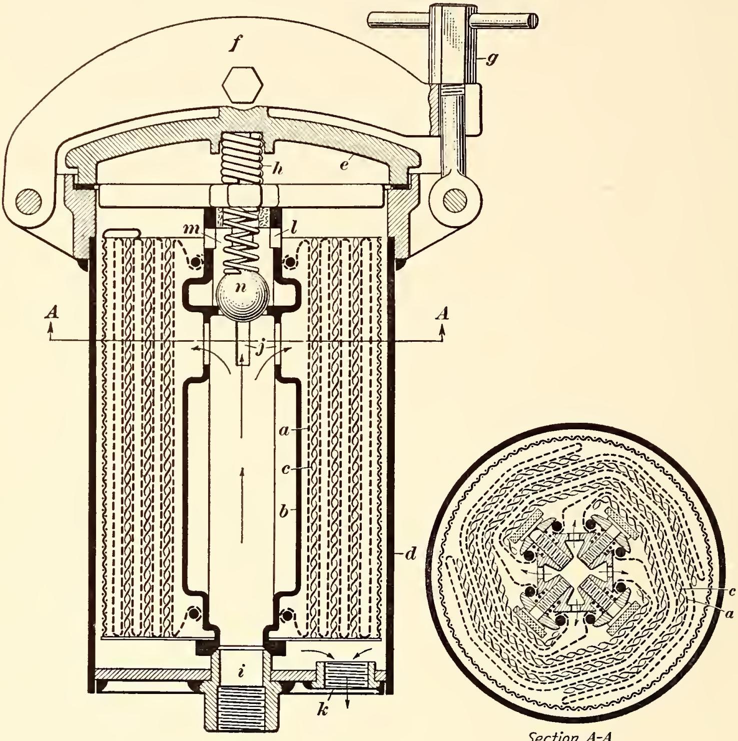
FIG. 22

74. Another type of edge filter is shown in Fig. 22 (*a*). The filtering element *a* consists of a flat metallic ribbon *b,* view (*b*), of bronze, monel metal, or stainless steel, wound on a corrugated frame *c.* The ribbon has a flat front edge and tapers in cross-section. It is provided at definite intervals with projections *d* of uniform height which act as spacers, so that their height determines the degree of filtration. Filters with different heights of spacers can be provided, the minimum height being .0005 inch. Oil enters the filter through the inlet *e,* view (*a*), and leaves through the outlet *f.* The dirt in the oil builds up in the form of a solid layer *g,* view (*b*), on the front edges of the ribbon. This layer of dirt tends to bridge over the slots between the ribbons, thereby removing smaller particles of dirt in the oil than the actual width of the slots. The tapered cross-section of the ribbon makes it impossible for any dirt that does enter the slots to wedge behind the front edges of the filtering element. From time to time the layer of dirt adhering to the filtering element is sheared off the ribbon by means of a spring bronze knife *h*, views (*a*) and (*b*), that is supported in a frame, which can be revolved around the outside of the filtering element by turning the handle *i*, view (*a*), in a clockwise direction. This handle is provided with a ratchet that prevents the knife from being turned in the wrong direction. The dirt sheared off by the knife falls into the sump at the bottom of the filter and is removed through the drain plug *j*.

It is very important that oil filters be cleaned regularly and any water accumulation be drained off. If the water is allowed to stay in the filter it may collect on the filtering element and prevent the oil from passing through. In cold weather this water may freeze and shut off completely all oil going to the engine.

75. Cloth Filter.—A longitudinal section of a cloth oil filter is shown in Fig. 23 (*a*), and in view (*b*) is shown a cross-section taken along *A-A*. The filter element consists of a cloth filter bag *a* made of felt, flannel, or wool, wound in several layers around a central hollow spool *b*, the layers of cloth being separated from each other by a metal spacing mat *c*. The rolled-up filter element is enclosed in a wire cage and lowered into a cylindrical shell *d*, which is then closed by a cover *e* that is clamped tight by means of a clamp *f* and clamp screw *g*. A spring *h* set in the cover *e* presses down on top of the central spool *b* and makes an oil-tight joint over the inlet *i* by which the oil enters the filter. After flowing upwards through the hollow spool, the oil enters the filter element through passages *j* in the spool. The cleaned oil leaves through the outlet *k*. If the filter bag should become fouled with dirt, the oil will overflow through holes *l* at the top of the filter element and enter the by-pass passage *m*, through which it is conducted directly to the bearings, without exerting any undue pressure on the filter element or causing a shut-down of the lubricating system. In case of excessive pressure of the entering oil, a spring-loaded ball valve *n* serves to relieve the filter by allowing the oil to enter the by-pass passage *m*.

76. Magnetic Strainers.—If the lubricating system also includes the lubrication of gearing, such as is the case in internal-combustion engine lubricating systems in which the timing gear train is lubricated by the same system as that provided for the bearings, small pieces of metal chipped from the gears may enter the system and clog the oil piping, besides abrading the bearings. In such cases a magnetic strainer may be used to good advantage in the suction line of the lubricating-oil pump. Magnetic strainers are designed with a diaphragm or basket having the properties of a permanent magnet, so that any particles of metal that



(a)

Section A-A
(b)

Fig. 23

may have been chipped from the gears will adhere to the diaphragm and will thereby be eliminated from the lubricating system.

OIL HEATERS

77. **General Requirements.**—It is sometimes necessary to employ oil heaters in engine lubricating systems, especially in cold climates, to enable the oil to flow freely through the system. With the use of certain types of oil filters it is often necessary to heat the used oil to about 150° F. in a separate heater before effective purification can take place. Storage tanks for lubricating oil are sometimes provided with coils of pipe through which steam is passed when it is desired to reduce the viscosity of the oil. Exhaust steam is commonly used for this purpose, though with very heavy oil and in cold weather live steam is needed. The exhaust end of the coil should be connected to an inspection tank, so that any leaks will be quickly noted by the presence of oil. Instead of exhaust or live steam, water heated by the exhaust gases from the engine is sometimes used to heat the lubricating oil.

78. A heater for any particular installation should be of such size that it will contain sufficient heating surface to raise readily the required quantity of oil from the inlet temperature to the desired discharge temperature. The amount of heating surface required for this purpose varies with different types of oil heaters and also depends on the steam pressure and the quantity of oil to be heated. Oil heaters should preferably be installed in duplicate or triplicate, so as to have one clean heater in reserve at all times. Steam traps should be installed in the drain lines from oil heaters to prevent water from accumulating in the heater, which would seriously interfere with the operation of the heater. Two general types of oil heaters are in use, namely, heaters in which the oil passes through coils and is surrounded by steam, and heaters in which the steam passes through coils and is surrounded by oil.

79. **Film Oil Heaters.**—The oil heater shown in part section in Fig. 24 is known as a film oil heater. Heaters of this kind are usually supplied in various capacities either as single

units or as multiple units. The units are connected by pipes so that each individual unit is under control and can be cut in and out independently of the others by means of valves. In this heater the oil surrounds the space containing the steam. The heater is built up of two concentric cylindrical shells *a* and *b*. The oil enters through the inlet *c* and takes a spiral course upwards between the two shells to the space *d* between the two shell heads from where it is discharged at *e*. Steam for heating enters through the inlet *f*, passes upwards through the pipe *g*, and enters the inner space *h*, the condensate being discharged through the outlet *i*. Both the inner and outer shells have flanges formed on the lower ends and are mounted with an oil-proof gasket between them to prevent the leakage of oil. The spiral oil passage is formed by welding a steel strip in a spiral shape on the outside surface of the inner shell. When it is desired to clean the oil passages, this may be conveniently done by removing the flange bolts *j* and pulling the inner shell *a* out of the outer shell *b*.

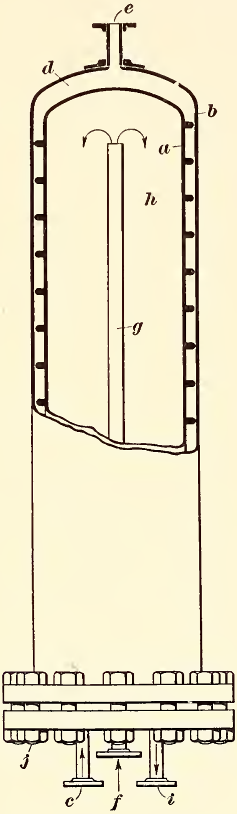


Fig. 24

80. Multi-Coil Oil Heaters.—A multi-coil oil heater is shown in Fig. 25. In this heater the oil flows through the tubes and is surrounded by the steam. One of the particular advantages of this type of heater is the peculiar construction used in connecting the ends of the coils to the outside manifold, by which the possibility of oil leakage inside the heater is practically eliminated. The shell *a* is constructed of welded steel piping, and fitted at the top *b* and bottom *c* with rolled steel flanges. Coils *d* of drawn seamless steel tubing are inserted in the shell. The number of coils fitted depends upon the quantity of oil to be heated and the temperature range. The coils are connected to the outside manifolds *e* by means of special screwed union joints. The side view shows the water gauge glass *f* and fittings *g*. By this the amount of condensate in the shell is observed. A pressure gauge *h* indicates the steam pressure inside the shell. The oil is admitted to the heater either at the top or at the bottom, and after passing through the coils in the heater, is discharged at the opposite end. Steam is admitted to the shell through the connection *i*, and the condensed steam passes out of the shell at *j*.

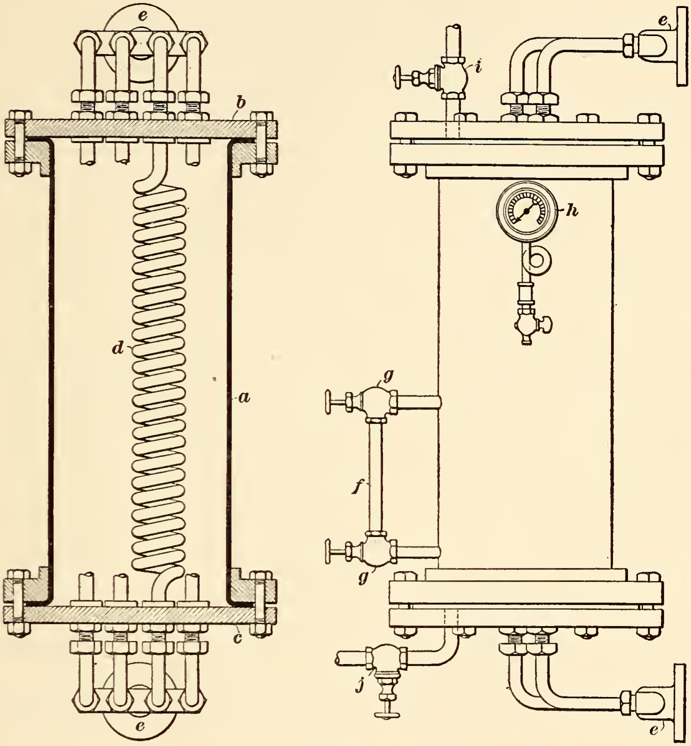


Fig. 25

81. **Tubular Oil Heater.**—In Fig. 26 is shown a tubular oil heater consisting of a vertical cylindrical steel shell *a* containing a number of tubes *b*. A header *c* containing the oil inlet *d* and the oil outlet *e* is fastened to the upper tube sheet and the cover *f*

is attached to the lower tube sheet. The steam inlet is shown at *g* and the condensate drain at *h*. A baffle plate, not shown, is provided inside the shell near the steam inlet, to prevent live steam from blowing directly against the tubes, and also to provide a more even distribution of the steam through the tubes. The heater is so designed that the oil is forced to make several passes through the tubes before it is allowed to leave. Vertical partitions in the upper and lower headers divide the tube nest in the proper manner to produce flow through the tubes in several passes. Expansion and contraction of the tubes are compensated for by bowing the tubes as shown. The tubes are of seamless steel rolled into the tube sheets and may be inspected and cleaned after removing the top header *c*. The holes at *i* are for thermometer connections.

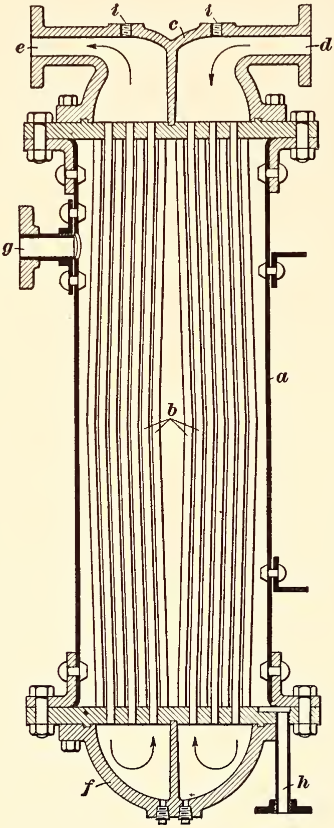


Fig. 26

OIL COOLERS

82. Purpose and Requirements of Oil Coolers.—The object of installing an oil cooler in the engine lubricating system is to dissipate heat generated in the bearings and absorbed by the oil, and to maintain the oil temperature at a suitable safe level, generally about 160° F. When the temperature of lubricating oil exceeds this value, the viscosity of the oil decreases to such an extent that the oil film between the bearing surfaces is liable to break down. Furthermore, the hot oil is easily oxidized and, in the presence of water and foreign matter, forms a sludge that obstructs the lubricating system. Oil coolers are also often used when it has been found necessary to heat the oil in a heater in order to obtain more effective purification. The oil is then cooled again before it is led to the bearings.

Oil coolers are generally simply heat exchangers; that is, the oil to be cooled is led into a vessel containing a large number of pipes through which a suitable cooling fluid is passed. The cooling fluid may be raw fresh water in the form of all or part of the engine jacket water, salt water, or condensed steam. The oil surrounds the pipes and gives off its heat to the cooling medium. If condensed steam is used to cool the oil, the heat from the bearings recovered from the oil may be returned to the boiler in the feedwater. The temperature drop through the cooler should not be allowed to exceed 30 degrees, as otherwise the oil will become too viscous to be an efficient heat carrier. It is possible to maintain the temperature of the oil within close limits by regulating the amount of cooling water passing through the cooler.

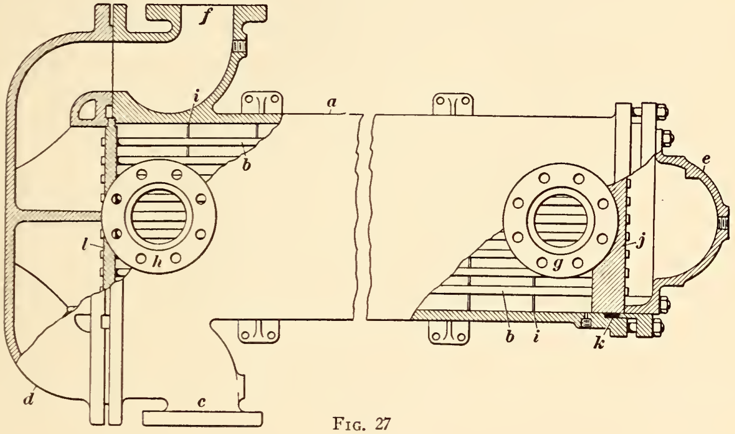


FIG. 27

83. Typical Oil Cooler Construction.—The oil cooler shown in Fig. 27 consists of a cylindrical shell *a* containing a removable bundle of tubes *b*, through which cooling water is passed. The water enters through the inlet *c*, flows through the bottom section of the head *d* and then through the lower half of the tube bundle into the head *e*, from which it returns through the upper half of the tubes into the upper section of the head *d*, finally leaving the cooler through the outlet *f*. The oil enters the cooler through the inlet *g* and leaves it through the outlet *h*, so that the oil flows through the shell in an opposite or counter-current direction to the flow of water in the tubes, thereby receiving the maximum cooling effect. Baffle plates *i* are mounted inside the shell to direct the flow of oil across the tubes and effect the most efficient heat transfer. In order to enable the tubes *b* to expand and contract independently of the shell, they are expanded at one end into a floating tube-sheet *j* that is free to slide in or out of the shell *a*. Leakage of oil is prevented by a stuffingbox *k* provided with graphited asbestos packing rings. The head *e* is bolted to the tube-sheet. At the opposite end the tubes are expanded into the stationary tube-sheet *l*. The head *d* is bolted to the shell *a* and can be easily disconnected to enable the tube bundle to be withdrawn from the shell for cleaning purposes, which may be accomplished without disturbing the pipe connections at *c* and *f*. After the tube bundle has been removed from the shell, the outside of the tubes may be cleaned by blowing with steam or by immersing the tubes in a tank containing a hot solution of cleaning chemical. Hard formations on the inside of the tubes may be removed by means of a rotary tube cleaner, whereas soft deposits are removed by flushing with water and brushing with a stiff wire brush.

LUBRICATION OF BEARINGS

84. Kinds of Bearings.—Bearings may be classified as journal bearings, thrust bearings, and sliding-contact bearings. Journal bearings are cylindrical and carry the load at right angles to the axis of the bearing. Thrust bearings differ from journal bearings in that the load is applied in a line parallel to the axis. Sliding-contact bearings are those bearings that support parts sliding over them, such as crosshead guides, slide-valve seats, etc. Each of the three main classes of bearings may be loaded in different ways. For example, journals may be subjected to a uniform load always applied in one direction, the journal velocity being constant; the load may be constantly shifting from one side of the bearing to the other and constantly changing in value, as in the case of crankpin bearings and main bearings of reciprocating engines. Then, in some bearings the motion of the journal is reversible, as when the direction of rotation of the engine is reversed. In the case of main bearings of reciprocating engines the pressure is greatest on the downstroke, in the lower half of the bearing at a point *a*, Fig. 28, a few degrees ahead of the vertical line *bc* representing the direction of the application of the load. The pressure decreases to a point *d*, diametrically opposite the point *a*, on the assumption that the shaft revolves in the direction of the arrow. On the upstroke, conditions are reversed, the greatest pressure being at the point *d* and the least pressure at the point *a*.

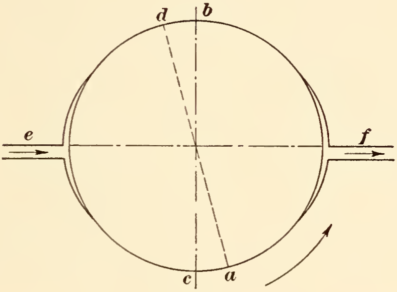


Fig. 28

85. Method of Lubricating Bearings.—The object of lubricating the bearings of an engine is to reduce friction to a minimum and to prevent the rubbing surfaces from becoming hot. Such heating, if the rubbing is continued without lubrication, will ultimately cause seizing, thereby permanently damaging the bearings and rendering the engine inoperative. The lubricant forms a thin film between the rubbing surfaces, and thus prevents the surfaces from coming into direct contact with one another. The oil film is caused by the rotation of the journal, which carries the oil around with it. With ordinary systems of lubrication, the lubricant should be delivered to the bearing at a point where the pressure is a minimum; that is, at the unloaded side, or upper half, of the bearing. If, however, the force-feed system of lubrication is used, the lubricant may be supplied at a point somewhat below the joint line of the bearing, as shown at *e*, Fig. 28, the rotation of the shaft causing the oil to be swept under the journal. The oil outlet is then fitted as shown at *f*.

86. In order to distribute the lubricant as uniformly as possible over the bearing surface, oil grooves are cut in the upper half, or low-pressure side, of the bearing. The oil that enters them flows toward the outer ends, thereby lubricating the journal. As a general rule, authorities are agreed that no oil grooves shall be cut in the lower halves, or high-pressure area, of bearings lubricated by a force-feed oiling system. On the other hand, it appears to be good practice to apply oil grooves in the lower halves also of large slow-speed reciprocating engine bearings, where there is excessive pressure and a large area to be lubricated, and where ordinary lubrication systems are used. Although oil grooves are necessary to keep such bearings reasonably cool, such grooves should not be applied in places where the pressure is greatest; that is, the grooves should not be at the bottom but about 45° off center, and they must not extend to the ends of the bearing, as this would permit the oil to run out of the bearing. Grooves applied correctly act as reservoirs to hold the oil so that it may be picked up and drawn into the high-pressure area out of which it might otherwise be squeezed. The grooves should be wide and comparatively shallow, and they may be cut in different forms, as X-shaped, circumferential, etc., care being taken to see that their edges are chamfered to prevent scraping the oil from the revolving journal. Oil grooves are never cut in the high-pressure parts of high speed bearings, such as are used in

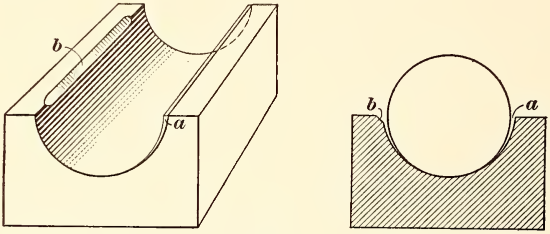


FIG. 29

steam turbines or reduction gearing, the speed of the journal in such cases being depended on to maintain a perfect oil film between the journal and the bearing surface and, in this case, grooves would break the continuity of the oil film.

87. The surface of the bearing metal in the lower halves of a main bearing should be eased off near the joints; this is known as side clearance and is shown at *a*, Fig. 29. In addition, a chamfer, as shown at *b*, should be cut on the edges of the joints between the bearing halves. These chamfers form oil pockets at the sides of the bearing, and this, together with the eased-off clearances referred to, causes an oil wedge to be formed that is drawn into the high-pressure part of the bearing by the revolving journal. Once the oil film is established between the journal and its bearing, it is maintained by a regulated oil-feeding process to make up for any oil that eventually works itself out at the ends of the bearings, and that is either lost, or recovered in a suitable container to be purified and used again.

LUBRICATION IN REFRIGERATION SERVICE

88. Influence of Body of Oil.—Reliability of compressor service can only be attained with the use of a lubricant that is correct in body, possesses high quality, and will therefore furnish lubrication with a very economical feed. Under normal conditions of operation the temperature of the surface of the water-cooled cylinder wall on which the oil is spread rarely exceeds 175° F. With this maximum temperature a medium-bodied oil will be thoroughly distributed over the cylinder walls and will seal the piston against leakage of gas past it. An oil of too heavy body will not be thoroughly distributed, and too light bodied an oil will fail to sustain the weight of the moving parts. Consequently, with an oil too heavy or too light in body, friction and metallic wear will take place, the piston seal will be broken, and the efficiency of the compressor will be greatly reduced. A medium-bodied oil will, therefore, best fulfil the pressure and temperature requirements encountered in the compressor cylinder.

The quality of the oil is an essential property influencing the amount of feed necessary for the maintenance of lubrication and the piston seal. An oil of poor quality will not maintain a lubricating film or piston seal unless fed in excessive amounts. Low-grade oils are not uniform and their body varies considerably over a narrow range of temperatures, so that with such oils a minimum feed cannot be relied upon.

89. Losses by Incorrect Lubricant.—The lubrication of the compressor cylinder and valves, considered alone, presents a problem not more serious than that of many other machines; but when the efficiency, capacity, and regularity of operation of the entire plant are considered the problems become more exacting and the possible losses through the use of incorrect lubricants become greater than in other industries. It is, therefore, necessary that the refrigerating plant be considered as a whole when selecting a lubricant for the compressor. Incorrect oils that foul the heat-transfer surfaces frequently reduce the output of the plant and increase the power required per unit of production to such an extent that the plant must be shut down for cleaning, the result being much loss of time and production, and even of perishable goods. When oil coats the condenser surfaces with even a very thin film, the heat transfer between the cooling water and the compressed gas is impeded enough to require an increase in the temperature difference between cooling water and condensing ammonia. Since the temperature of the cooling water is fixed, this necessitates a rise in the condensing temperature, with a corresponding increase in head pressure. This alone necessitates an increase in the pressure against which the compressor must work and, therefore, demands greater power.

90. Congealing and Decomposition of Oil.—Oil collecting in the evaporating coils is even more objectionable, as it influences both power and refrigerating capacity. Even a small quantity of oil congealing in the coils will so impede heat transfer as to require a material increase in the temperature difference between the evaporating ammonia and the substance cooled in order that the necessary refrigeration may be accomplished. The necessary reduction in the temperature of evaporation, in turn, demands a lower back pressure in the system, which again increases the work required by the compressor per ton of refrigeration produced. In addition to these large losses from oil-insulated heat-transfer surfaces caused by the use of unsuitable oils or the feeding of oil in excess to the cylinders, there are other objectionable results. Oils that are not suitable are frequently subject to decomposition in the system and may cause the formation of gases, which still further increases the power demanded by the compressor and further impairs heat transfer.

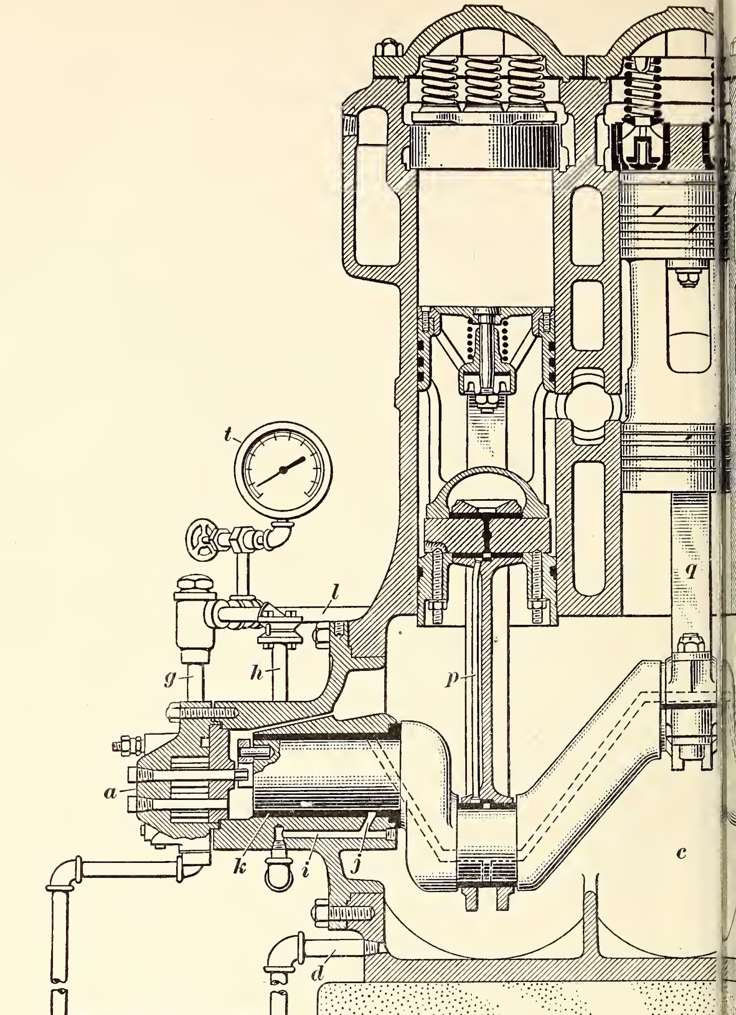
91. Essentials of Correct Lubrication.—The foregoing losses are all additional to the destructive effects of wear and depreciation experienced in all machines due to the use of incorrect lubricants. On account of the serious consequences of incorrect refrigerating plant lubrication, the following essential factors of correct lubrication are of extreme importance: The properly selected oil must not congeal, must not break down and form gummy deposits or gaseous products, and must be of sufficient body to lubricate and seal the compressor piston against leakage and avoid being readily atomized or swept out of the cylinder by the flow of the compressed refrigerant and so be carried through the system and deposited in the condensing or expansion coils.

When the lubricant in the compressor cylinder also serves as a seal for the gas valves, it is necessary that the oil should possess a high degree of cohesiveness, that it should not congeal at a low temperature, say 5° to 10° F. below zero, and that it should not saponify when in contact with alkalies. It should have a specific gravity of about .875, or a reading of about 30° on the Baumé hydrometer, and should have a flash point of from 300° to 325° F.

92. Oil for Ammonia Compressor.—Only a strictly pure mineral oil that has been filtered and distilled should be used for lubricating the cylinder of an ammonia compressor. In addition to being able to meet the cold or pour test, that is, to pour freely at temperatures of from zero to 10° below zero, it should also have a high flash point, since the temperature of the gas leaving the ammonia cylinder is often as high as 250° or 275° F., and oil of a low flash point would vaporize and decompose, causing the formation of non-condensible gases in the system. Also, if oils of low flash point are used too freely, oil and gas explosions are likely to occur, causing damage to the plant and possibly loss of life.

For compressor lubrication, a straight distilled mineral oil having a viscosity of approximately 100 seconds Saybolt at 100° F. should be used, when the temperature of the gas entering the compressor is below zero Fahrenheit. When the suction gas has a temperature above zero, an oil having a somewhat higher viscosity, say 200 to 300 seconds Saybolt, will give somewhat better results. Such oils will have a wide enough range of physical properties to lubricate compressors satisfactorily under the usual operating conditions. Care should always be exercised to prevent water from getting into oils used to lubricate the compressor cylinder, since water carried over into the cooling coils is likely to freeze, the result being a decrease of evaporating efficiency. It is likewise necessary to control the amount of oil introduced into the compressor cylinder, as oil reaching any part of the cooling system will tend to adhere to the inner surfaces of the coils; and since oil is a poor conductor of heat, the evaporating efficiency of the coils will be reduced, just as when water finds its way into the system. It may happen that the engineer in charge of a refrigerating plant is compelled to operate a machine for a time with worn or scored cylinder walls and piston rings. In order to lubricate such machines with any degree of success, an oil of somewhat higher viscosity is required. The use of animal oils to lubricate refrigerating machinery has been entirely abandoned.

93. In the operation of any refrigerating or ice plant, a daily record should be kept of the actual oil used each day, and this should be compared with the oil removed from the system from time to time when draining the oil separator on the discharge pipe and other parts of the system where provision is made for removing oil. The two should check fairly closely. The engineer should always use sufficient oil in the compressor to insure adequate lubrication, but oil should not be used to excess, since a comparatively small quantity of high-grade oil



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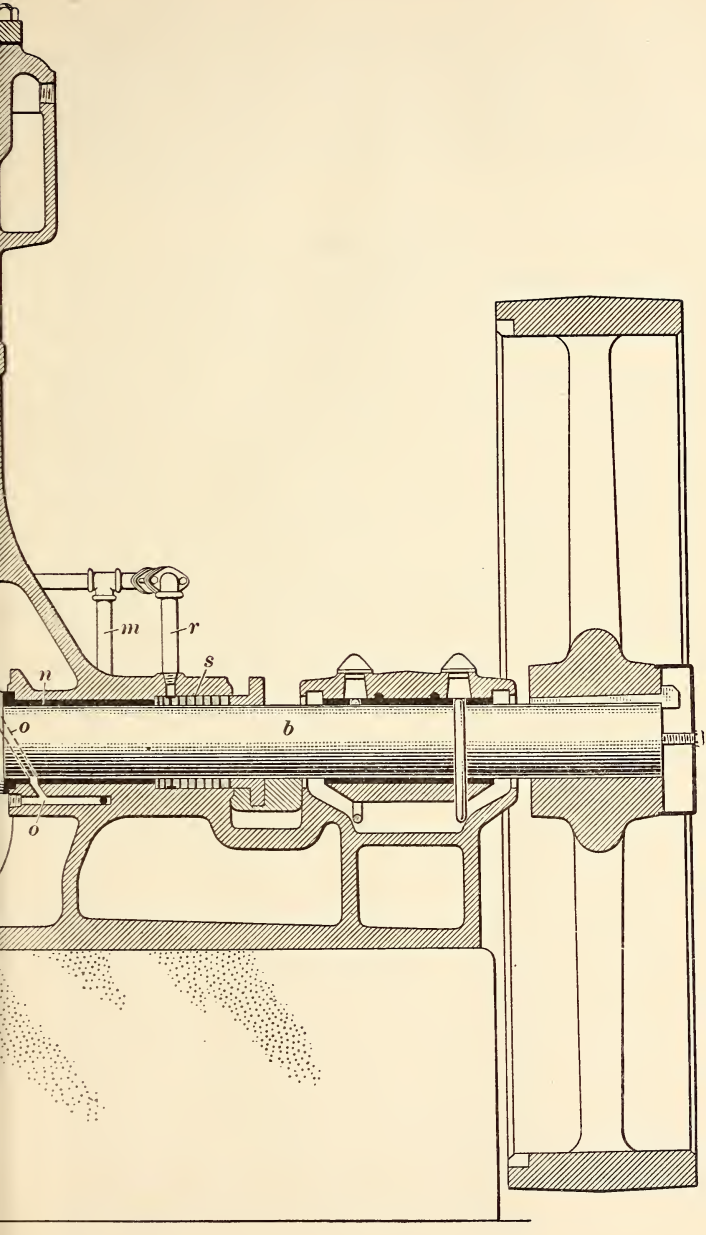
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will lubricate a great amount of cylinder surface. The correct amount for any given machine may be determined by experiment and by examination of the cylinder walls to determine whether or not they show a good oil film. If the walls appear somewhat dry, the indication is that an insufficient amount of oil is being supplied.

94. Until recent years only the largest sizes of enclosed-crankcase compressors employed a force-feed or pressure system of lubrication. In modern practice force-feed lubrication is used on practically all sizes of vertical enclosed compressors having cylinder dimensions larger than $4\frac{1}{2} \times 4\frac{1}{2}$ inches. By this method oil under pressure is supplied to the main bearings, crankpin bearings, and piston-pin bearings, as well as to the compressor cylinders. By using pressure lubrication very little oil remains in the crankcase and a more accurate control of the amount of oil delivered to the cylinders and bearings is possible. With this system a force-feed lubricator or oil pump is driven from the machine crank-shaft, permitting the oil to be circulated continually and the oil from the bearings returned through a filter by which any foreign matter is removed.

95. In Fig. 30 is shown a vertical enclosed-type ammonia compressor which is lubricated by means of an oil pump *a* driven directly from the crankshaft *b*. Oil that collects in the bottom of the crankcase *c* drains through the pipe connection *d* to the oil purifier *e* whence it passes through the pipe *f* to the pump *a*. The pump supplies oil under pressure through the pipes *g* and *h* to the passages *i* and *j* that conduct the oil to the bearing *k*; likewise, another pipe *l* conducts oil through a pipe *m* and drilled passages, not shown, to the bearing *n*. From the main bearings lubricant is supplied to the crankpin bearings through channels *o* drilled in the crank webs and crankpins. From the crankpins the oil is conducted to the piston-pin bearings through oil tubes *p* fastened to the connecting-rods *q*. A branch pipe *r* carries oil to the packing of the stuffingbox *s*. A pressure gauge *t* is provided to indicate the pressure at which the lubricant is delivered to the bearings.

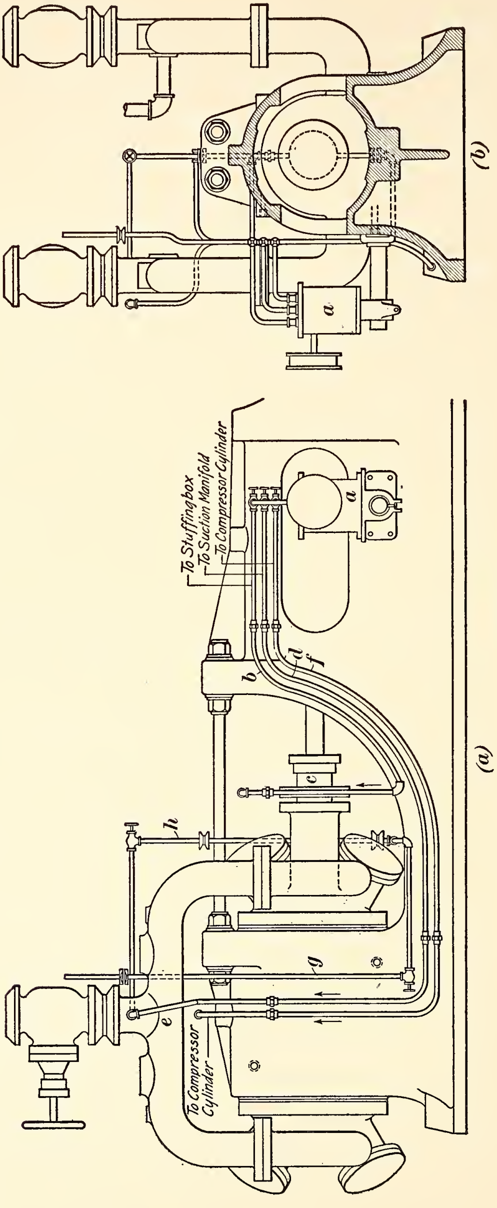
a
(b)
To Stuffingbox
To Suction Manifold
To Compressor Cylinder
a
b
d
f
c
h
g
e
To Compressor Cylinder
(a)

Fig. 31

96. Another typical oiling system for a compressor cylinder is shown in Fig. 31 (*a*) and (*b*). A belt-driven oil pump *a* is carried by a bracket at the side of the frame and from it lead three discharge lines. The line *b* conveys oil to the stuffingbox *c,* where it lubricates the packing and the piston rod. A part of it escapes at the outer end of the stuffingbox and is caught in the compressor bed. The remainder works along the rod into the cylinder and helps to lubricate the cylinder and piston. The line *d* leads oil to the suction manifold *e,* and this oil is carried into the cylinder by the entering gas, lubricating the valves and the cylinder. The third line *f* leads directly to the top of the compressor cylinder and furnishes lubricant to the piston and cylinder. The regulating valve on each line is opened just enough to pass the amount of oil required. In some cases, the oil escaping from the stuffingbox is sufficient to lubricate the cylinder. A liquid ammonia line *g* is connected to the stuffingbox, so that, in case the piston rod runs hot, cooling may be done by the expansion of ammonia. The line *h* returns the expanded ammonia to the suction manifold.

97. Mechanical lubricators are frequently used for supplying oil under pressure to both horizontal and vertical ammonia and carbon-dioxide compressor cylinders. In the case of the enclosed vertical compressor, the oil pump is generally driven by a belt from a pulley on the crankshaft. This is shown in Fig. 32, which is a view of a large enclosed-type compressor. It will be noted that the lubricator oiling system is entirely separate from the bearing pressure lubricating system. A pulley *a* on the crankshaft drives a pulley *b* on the shaft of the lubricator *c* which supplies oil under pressure to the cylinders *d* and *d'* through two oil lines *e* and *f,* respectively. A third line *g* leading from the lubricator introduces oil into the suction gas pipe *h* just before it enters the compressor. The pressure lubricating system for the bearings is operated by a pump *i,* the suction valve being shown at *j* and the discharge valve at *k.* The pump *i* is driven from the end of the crankshaft as in Fig. 30. The oil in the mechanical lubricator is replenished at definite intervals of time.

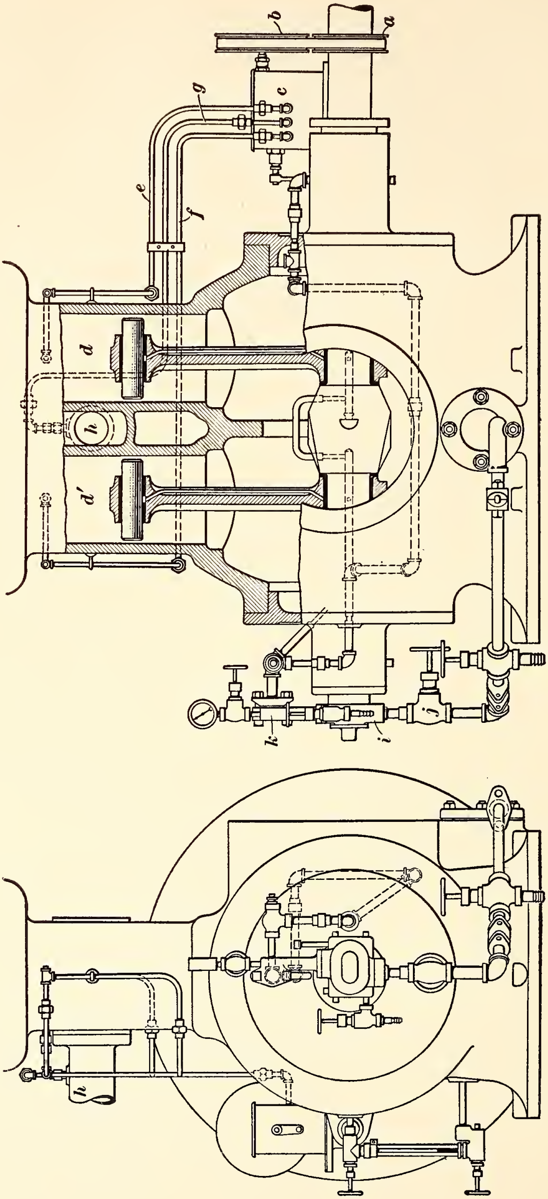

Fig. 32

LUBRICATION AND COOLING TROUBLES AND REMEDIES

Serial 5253 Edition 1

FAULTY OPERATION AND ADJUSTMENT

SYMPTOMS, CAUSES AND CORRECTIVES

LUBRICATION TROUBLES

1. **Troubles in Lubrication Systems.**—Proper lubrication of all wearing parts of an internal-combustion engine is of vital importance in keeping the engine running at maximum efficiency. Many engine troubles may be avoided by inspecting the lubrication system of the engine at regular intervals to check whether the lubricant is being delivered to the cylinders and bearings in sufficient quantity and at the proper pressure. The oil used in the system should be of the very best grade obtainable and should conform to the manufacturer's specifications. The grade of the oil should be such as to adapt it to the particular service to which the engine is put, so that the oil film in the bearings will not break down under the load imposed on the bearings. Faulty engine operation is often the result of an inadequate supply of lubricant, or the use of a grade of oil that is not suitable for removing the heat developed in the bearings. Every precaution should be taken to prevent water from entering the lubrication system, as it not only causes the oil film in the bearings to break down prematurely but also corrodes the journals. All oil reservoirs should therefore be examined frequently for presence of water, and if any is found, they should be drained until only pure oil remains. Water may enter the lubrication system through leaks in the water-circulation system, through vents on oil reservoirs, or because of leaky tubes in the oil cooler.

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2. Several methods are employed to remove water from lubricating oil; the water may be settled out by heating the oil after it has been withdrawn from the system, or the water may be removed by passing the oil through a centrifugal separator. Many engine installations have such a separator installed as part of the regular equipment. The best place for the separator is between the crankcase sump and the oil filter. The condition of the lubricating oil in the lubricating system must be constantly watched to see that the oil maintains the correct viscosity at the working temperature of the engine. Even in the best lubricating systems the crankcase oil will become diluted in time by dirty oil from the cylinders leaking past stuck piston rings, or through other leaks. Lubricating oil that is not passed through a centrifuge at regular intervals should be withdrawn from the system after a certain time of service, and replaced by fresh oil after the crankcase has been thoroughly cleaned out with kerosene. The breather on the crankcase should always be maintained in good working condition to prevent building up a pressure in the crankcase, which might cause the lubricating oil to work out of the bearings.

If the lubricating oil is run through an oil cooler, and the temperature of the oil leaving the cooler should show a sudden increase, the trouble is very likely due to insufficient water passing through the cooler or to dirty condition of either the water space or of the oil pipes. Sludge formed on the outside surfaces of the tubes prevents the efficient transfer of heat and should be removed. If a strainer is fitted on the inlet side of the cooler it should be kept clean to prevent excessive pressure drop through the cooler.

3. Excessive lubrication of an engine is fully as bad as under-lubrication and neither should be permitted. A sudden increase in the normal oil consumption of an engine is generally an indication of leakage of oil at some point in the lubricating system, usually at a joint in the oil piping, and such leaks should be attended to at the first available opportunity. It is of the utmost importance to clean all strainers in the lubricating system of accumulations of dirt, grit, or other foreign matter such as rust from pipes or tanks, at regular intervals. Care should be taken never to use waste in cleaning oil reservoirs, bearings, or any part of the lubricating system, as lint from such waste will invariably find its way into the pump suction or into the oil leads to the bearings. If it becomes necessary to wipe the inside of an oil tank, rags or heavy toweling should be used instead of waste. When the strainers and the oil cooler in the lubricating system are maintained in good operating condition, and a centrifugal purifier is used to clean the oil at regular intervals, troubles originating from impure lubricant need never be considered in the operation of any internal-combustion engine.

4. **Lack of Lubricating Oil.**—The chief causes of insufficient lubrication are lack of oil in the oil reservoir, usually due to carelessness or forgetfulness on the part of the operator, and obstructions in some part of the lubrication system which prevent the passage of the oil. Insufficient bearing lubrication may also be caused by insufficient pressure in the lubricating system because of wear of the bearing surfaces, dirty or worn-out condition of the lubricating oil, or loss of suction of the lubricating-oil pump.

If during the operation of an engine, the oil supply should fail either from the supply in the crankcase, lubricator, or other sources having become exhausted, or from failure of the lubricating system to deliver the oil properly, the engine must be stopped immediately to prevent serious damage to its parts. Practically all engines are equipped with some ready means of noting the action of the oil, such as sight feed glasses and oil gages of various types. The operator will do well to glance at these indicators frequently, as it may be the means of preventing expensive repair bills.

5. Small and medium-size internal-combustion engines are usually supplied with oil from a reservoir contained in the crankcase. Large engines are in many cases provided with an oil reservoir that is located below the engine-room floor. The oil pump used for forcing the oil from this reservoir to the

manifold, or main, from which the bearings are supplied may be of either the rotary or the plunger type, and may be driven either by an electric motor or by the engine itself. Any excess oil not passed to the bearings is by-passed back into the reservoir. Used oil from the bearings collects in the crankcase, from which it is returned to the reservoir by gravity.

Leaks in the suction pipe, or failure of the pump suction because of too low level of the oil in the reservoir, are preventable. The suction pipe must be absolutely airtight, or the oil will not be drawn from the oil reservoir to the pump. When the oil pump has been removed and taken apart, it is usually necessary to prime it, or fill it with oil, when it is assembled again in order to start it worknig. If the pipe line is stopped up, each section should be removed separately and a wire run through it to remove any dirt or foreign matter it contains, then it should be washed by running kerosene through it. A sudden rise of pressure on the gage may indicate a stoppage in the delivery pipe from the lubricating pump. If the pressure shown on the gage should drop after the bearings have been overhauled, the trouble may be due to excessive bearing clearances, or to improper fitting of the shims in main-bearing and crankpin boxes, allowing the oil to leak out of the ends of the bearings.

6. The first indication of a lack of oil is a sudden sluggish action of the engine with a material falling off in power. Unless the engine is stopped and examined to ascertain the cause of lack of oil supplied to the cylinders, there will be further symptoms in the shape of dry, wheezy sounds, and smoking from openings in the crankcase or base of the engine. If the cause of the trouble is not determined and remedied, the babbitt will be melted out of the bearings; this condition will be manifested by a terrific hammering and rattling of the engine. It is extremely dangerous to run the engine after this stage has developed. The result of the lack of oil in the cylinders is the scoring of the piston and cylinder wall, and the loss of spring in the piston-rings, usually requiring reboring of the cylinders and the renewal of the pistons and rings.

Whenever an engine has been without oil or when the pistons have been placed in the cylinders after having been removed, a little oil should be squirted onto the top of the piston, so that there will be sufficient lubrication between the piston and the cylinder wall until the oil has had a chance to reach them from the regular sources.

7. Too Much Oil in Cylinders.—Too much oil in the cylinders of an internal-combustion engine is usually indicated by a smoky exhaust and may decrease the efficiency of operation of the engine to a considerable extent. If the oil supply is not cut down promptly, there will soon be an accumulation of carbon on the piston and cylinder walls, as well as in the piston-ring grooves. Over-lubrication of the cylinders of a gas or gasoline engine may cause the sparkplugs and valves to become fouled. The accumulation of oil on the sparkplugs, in turn, may cause misfiring by short-circuiting the contact points. In a Diesel engine, excessive cylinder lubrication may cause an accumulation of carbon on the tip of the fuel valve as well as on the valve seats, thereby creating serious operating troubles.

Regardless of the type of lubricating system used, it is generally true that pouring too much oil into the crankcase will give excessive cylinder lubrication. The remedy is to draw off oil until the correct level again obtains. In pressure-feed oiling systems of the high-pressure type, the relief valve of the oil pump may be set for too high a pressure, the remedy being to readjust the relief valve for a lower pressure. When a cylinder lubricator is used on an engine, the feed may be such that the oil will be given to the cylinders at too high a rate. The remedy is to cut down the feed as soon as white smoke is observed in the exhaust.

8. Where no provision is made for controlling the supply of oil to the cylinders, the amount which gets past the pistons into the combustion chamber can be diminished to some extent by cutting or filing away part of the lower wall of one or both of the two lower grooves of the piston, as shown at *a* and *b*,

Fig. 1, and drilling small holes *c* about $\frac{1}{32}$ inch to $\frac{1}{16}$ inch in diameter at regular intervals around the groove and slanting downward about 45 degrees, as shown at *d*. The larger the holes and the greater the number of them the more effectively will the oil be collected, and returned through the holes to the crankcase. It is best to begin with one groove and a few small holes and increase the number each time the engine is overhauled until the over-lubrication trouble disappears. A good way to file this groove is to use a piece of wood 2 or 3 inches in width and of the right thickness to fit snugly in the groove so it will not slip as the file is rubbed against it; then with this as a guide use the edge of the file to make the notch as shown at *a* and *b*, the notch being made about equal in depth all the way around the piston. This notch should not be more than one-fourth of the depth of the groove in which the piston-ring fits.

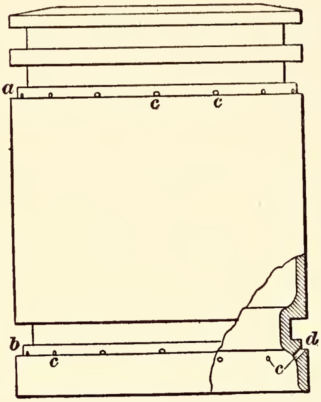


FIG. 1

9. Improper Oil in Cylinders.—In the operation of a gas or gasoline engine, the trouble symptoms produced by the use of oil unsuited for lubricating the piston are white or yellow smoke in the exhaust, rapid fouling of sparkplugs, partial clogging of inlet and exhaust valves, and rapid accumulation of carbon on the valves, in the combustion chamber, and about the piston-rings.

To remedy the trouble, inject kerosene freely through the priming cock to loosen the carbon deposit on the piston-rings, and use kerosene to free the valves if they stick. Drain the crankcase, and clean the entire system out with kerosene. Drain off all kerosene, and refill the oiling system with a good grade of cylinder oil of the kind recommended for the particular engine at hand. The carbon deposit should be removed and the sparkplugs cleaned off, then the engine will be ready to operate again. Considerable white smoke will come from the exhaust at first, but this will soon wear off.

10. Precautions to Be Taken in Pressure-Lubricated Engines.—Since, in a pressure system of lubrication, the oil is circulated at a pressure varying from 10 to 60 pounds, any foreign matter, such as metal cuttings, carbon particles, or dust, will, if not intercepted by some means, be passed through between bearing surfaces to produce premature looseness. Trouble also may be encountered with water collecting in the system from leakage and producing frothing, sludging, or emulsification of the oil. When water collects in the drilled passages of the crankshaft and the engine is left standing in cold weather, the result may be the cracking of the crankshaft, or, more usually, the forcing out of the plugs or other devices used to seal the oil passage holes in the shaft journals and pins. If the piston-ring design is not adequate to handle an excessive amount of oil, wear in the bearings may cause a surplus amount to be thrown out to flood the cylinders and produce what is commonly known as oil pumping.

11. As a general rule, the following points should be observed on pressure-lubricated engines:

1. Oil-pump screens should be examined frequently and cleaned at regular intervals.
2. Crankcase breather screens should be kept intact so as to eliminate the possible entry of mud, dust, etc.
3. Felt washers and other sealing devices should be examined when the engine is being worked on, and these parts should be renewed if they show signs of wear.
4. While repair work is being done on the engine involving drilling, filing, or chipping operations, the oil pan should be removed and cleaned before the engine is restarted; likewise all interior parts of the engine should be cleaned. This precaution is to prevent cuttings from passing through the screen and to the bearings.
5. The presence of water or sludge formation in the oil pan should be carefully guarded against. If the removal of the pan shows this formation, investigate the cause and correct it

as soon as possible. Water leaks, poorly fitting piston rings, and inferior lubricating oil are frequent causes. Insufficient heat to the inlet manifold or a non-volatile fuel are also contributory causes.

Dilution without sludge or solid matter is not generally injurious, and a thin oil free from solids is safer than a heavy-bodied oil carrying solid matter in suspension.

6. The lubricating-oil pressure gage should often be consulted so as to get some idea of the general condition of the lubricating system. The operator should not, however, tamper with the seating of the pressure-relief valve in an effort to increase the oil-gage reading. When once correctly set, the pressure-relief valve should remain so almost permanently. Increasing the spring tension by stretching or adjustment should be resorted to only when it is positively known that the bearings are properly adjusted, that the sealing devices are intact, and that the end clearances at moving parts are correct.

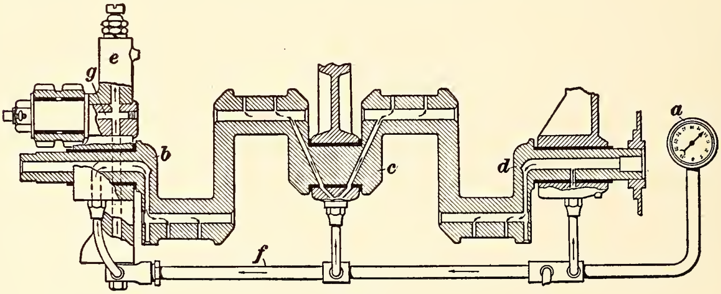


Fig. 2

12. High Gage Reading.—Generally speaking, an unusually high reading on the lubricating-oil pressure gage indicates an obstruction at some point in the oil circuit between the gage and the pressure-relief valve. This is not always true, however, owing to the different locations of the gage in the circuit. In an installation such as is shown in Fig. 2, an excessive reading of the gage *a* would indicate an obstruction in one of the three main bearings *b*, *c*, or *d*, probably in the front one, or *b*, as an obstruction in the rear ones would allow part of the oil to escape through the pressure-relief valve *e*, or regulating-screw assembly. If the gage were placed at the front end of the oil-distributing pipe *f*, an excessively high reading would indicate an obstruction either in the front main bearing *b* in the chain-sprocket passage *g*, or a derangement of the pressure-relief valve, causing the valve to remain on its seat.

Other conditions that could produce a high reading are oil that is too heavy, bearings too tight, derangement of the pressure-relief valve, or a defective gage. The last is rarely encountered and, if the gage hand returns to zero when the engine is stopped, it is a fairly accurate indication that the trouble is not in the gage. If the bearings do not have sufficient diametrical clearance, which could be the case where they had been recently adjusted, excessively high pressure will result. In the case of the pressure-relief valve, this should be set according to the recommendations of the engine manufacturer. Unless the valve is wedged or seized tight on its seat, it is probable that the trouble will be found elsewhere.

If none of the foregoing suggestions locate the cause of the high gage reading, the operator can locate the exact source of the trouble by loosening, one at a time, the joints of the oil pipes on the discharge or outlet side of the pump circuit. If, when the engine is running, a point is found where there is no oil leaking from a joint that was loosened, it indicates that the obstruction lies in the bearing or passage nearest to the pump.

13. Low Gage Reading.—An unusually low reading on the lubricating-oil pressure gage is indicative of the following general conditions.

1. Wear in pump parts.
2. Improper adjustment of the oil pressure-relief valve.
3. Oil supply in the engine too low.
4. Oil too thin.
5. Dirty or partially obstructed screen.
6. Obstruction in the suction passages.
7. Too much clearance or end play at the bearings.
8. Leaks somewhere in the pipes or passages.
9. Defective gage.

14. Wear in the parts of a gear-type oil pump is a frequent cause of low pressure. There should be not more than .0015 inch clearance between the outer edges of the gear-teeth and the bore of the pump casing. If the clearance is in excess of .003 inch, the casing or gears should be replaced. The clearance between the top of the gears and the cover on the top of the pump casing should be not more than .002 inch. If the clearance is greater than this, the coverplate should be removed and a thinner gasket should be substituted for the original one. If a thinner gasket cannot be installed, it will be necessary to lap down the top face of the pump lower housing on a piece of emery cloth, stretched over a smooth board or over a surface plate. The oil-pump line may be checked as follows:

1. Where the oil pump is externally located or where the packing-gland pump shaft is not submerged in oil, it is advisable to check for leakage at this point. An air leak at the gland will result in an intermittent action of the pump and low pressure. Oftentimes, also, it will necessitate the priming of the pump after the engine has stood idle for some time.

2. If the pressure-relief valve was correctly set in the first place, it is not likely to be the cause of the low pressure. In case other points are checked and are found correct, however, it will be advisable to remove the pressure-relief valve assembly and examine it for a broken spring, foreign matter on the seat, or a bent, worn, or broken valve in the regulator.

3. It is a simple matter to check the amount of oil in the engine pan or oil compartment. It is possible, however, for the oil-level gage to be deranged, and this derangement would cause it to register full when the compartment is empty or nearly so. To make a positive check, drain the oil pan and at the same time note the reading of the oil-level gage. If the gage is in working order, it will record the lowering of the level as the oil is draining, and will register zero when the case or compartment is empty. Refill, and if the gage moves toward the full mark as the oil is being poured into the compartment, it may be said to be in working order.

4. If the oil is too thin, the gage reading will be lower than normal, owing to leakage of oil past moving parts at both the

bearings and at the pump. The quickest remedy consists in filling the oil pan or the oil compartment with new oil.

5. The only test that can be applied to detect a partially obstructed screen is to remove it and apply a visual examination. If the engine is equipped with an outside oil filter, it will be advisable to examine the filter element for obstructions and sludge formation. If oil passes through the outlet side of the filter in normal quantity, the filter is not obstructed.

6. A partial obstruction in the suction or inlet pipe to the pump, or in the discharge line from the pump between the pump and the gage, will show a low gage reading. On the installation as shown at Fig. 2, the obstruction would occur between the pump and the gage, although an obstruction in any of the main bearing passages would show as a high reading instead of a low gage reading.

If the leads to the oil pump are easily accessible, the operator can disconnect the line at the discharge or outlet side of the pump. The engine is then briskly turned over by hand or it may be operated for a few revolutions under power. If a full heavy oil stream comes out of the pipe, the suction side of the circuit is good. If a full stream does not show, it indicates an obstruction or a partial obstruction in the suction, or inlet, side of the pump. Next, the line to the gage is disconnected and the engine is cranked. If a full stream shows, the trouble is in the gage; if a small stream, or no stream, appears, it indicates an obstruction in the passages between the outlet side of the pump and the point where the gage is connected in the circuit.

15. Oil Gage Does Not Register.—If, when the engine is started, the oil pressure gage does not register pressure, it is advisable first to check the oil-supply level. If checking this point shows a low oil supply, add enough oil to bring the level to the full mark. If an examination shows that the oil level in the pan is three-quarters full, prime the pump with oil from a squirt can. When the pump is externally mounted it will usually be provided with a plug, which can be removed to introduce the oil for priming. If priming the pump causes the gage to register, it indicates probable wear in the pump or a slight air leak at some place in the suction, or inlet, pipe to the pump. Use new oil of medium body for priming the pump.

In cold weather the failure of the oil pressure gage to register pressure may often be traced to the congealing of the oil in the line to the gage. Another frequent cause is sludging or ice formation at the pump inlet or screen. To determine if the failure of the gage to register is in the gage proper, disconnect the pipe connected directly to the pump outlet, and then crank the engine by hand or run it under its own power. If a solid stream of oil comes from the pump, it indicates an obstruction at some place between the pump and the gage or in the gage line.

16. Precautions to Be Taken in Splash-Lubricated Engines. Simplicity and the ability to supply oil to the cylinder walls immediately after the engine is started, are the main advantages of the splash system of lubrication. Very little attention is required to keep such systems at 100 per cent efficiency. If, in a splash-lubricated engine, there are indications of overoiling or oil pumping when it is known that the rings and cylinder walls are in good condition, the position of the holes in the oil-trough distributing pipe should be checked. Normally, the pipe should be so turned that when oil is forced into it from the pump, or from the test-tank outfit, the stream will be directed low enough to clear the big end of the connecting-rod, when the latter is at the bottom center position. If the pipe has been turned too far during the assembly, the holes may be so alined as to cause the oil stream to strike the lower end of the rod and result in overoiling.

17. Another point that should always be checked when complaint is made of either under or over lubrication, is the depth of the oil dippers at the bottom of the connecting-rod caps. The length of these dippers in connection with the height of the oil level in the subbase or oil troughs, determines the amount of oil that will be splashed, and consequently affects the degree of lubrication of both the lower connecting-rod and piston-pin bearings. In every case it is advisable to secure the recommendations of the manufacturer of the engine, although too much dip is less harmful than too little. Adjustment of the degree of dip is secured either by altering the length of the dippers, or by raising or lowering the level in the sub-base or oil troughs.

OIL LEAKS

18. Main-Bearing Leak.—Oil leakage through a main bearing is most often encountered on engines lubricated by the pressure system, although now and then the trouble is found on one oiled by splash. The theory of the cure is the same for the various individual makes of engines, but the particular construction determines the exact details to be followed. Fig. 3 represents a main bearing on a typical engine, which has been constructed to eliminate oil leakage. An annular oil-trap groove cut into the main-bearing cap is shown at *a*, *b* is the oil-supply lead to the bottom-bearing half, *c* is a passage leading back to the oil sump, and *d* is a threaded oil slinger on the crankshaft *e*, the purpose of which is to throw the oil back toward the crankshaft, and thence to the oil sump.

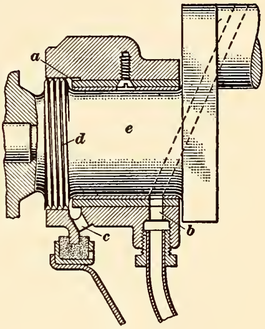


FIG. 3

19. Cam-Shaft Bearing Leak.—Oil dripping from the plug in the bottom of the flywheel housing usually indicates a leak at the rear main bearing, but, in some cases, it may be at the rear cam-shaft bearing. A leak at this point is usually caused by end play in the cam-shaft, which allows the shaft to slip back and forth in its bearings. Each time that the cam-shaft shifts toward the rear, it either bumps the washer that is pressed into the outer end of the bearing or builds up an excessive oil pressure between the washer and the shaft. The bumping action or the high oil pressure will loosen the plug, thereby causing it to leak into the flywheel housing. If new timing gears are being installed in an engine, exceptional care should be taken not to drive the cam-shaft against the washer in the cam-shaft bearing, as this will also force the plug out of place. In other words, when installing the cam-shaft gear, a pusher-type gear puller should be used instead of driving the gear into place with a brass hammer.

20. In Fig. 4 is shown the rear cam-shaft journal *a* of an automotive gas engine, the journal bearing *b*, and the bearing washer *c*. To stop an oil leak at this bearing it is necessary to remove the transmission, the clutch, and the flywheel in order to gain admittance to the washer *c*. In some cases it is also necessary to remove the flywheel housing. The washer *c* should always be replaced by a new one, as it is practically impossible to use the old washer and make it hold the normal oil pressure of the engine. The cam-shaft should also be inspected for end play and if this is found to be excessive, it should be removed by means of shims placed behind the timing gear or by installing a new lock pin, which in some engines is located near the center cam-shaft bearing and can be replaced without dismantling the engine.

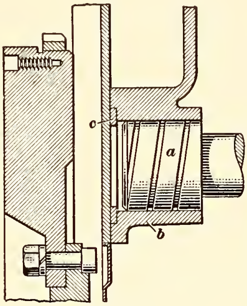


Fig. 4

If the timing-gear casing leaks oil because the bolts holding the casing have become loose as a result of engine vibration, it is sometimes possible to stop this oil leak by tightening the cover bolts. However, if the tightening of the bolts fails to eliminate the leak, it will be necessary to install a new gasket in the timing-gear housing.

BEARING TROUBLES

21. Main-Bearing Construction.—The crankshaft journals of stationary internal-combustion engines are generally supported in bushings, or shells, made in halves. These shells are mounted in seats machined in cross-members of the engine bedplate, a cap bolted to the bedplate holding the upper and lower halves of each bearing together. To secure perfect alinement of all main bearings the seats are generally bored at one setting, and in the better class of engines, the bottom shells are scraped to a fit in the seats. The process of scraping two surfaces to a fit will be described in a later article. The two bearing halves are lined with babbitt or some other suitable lining material and are mounted with shims between the joints in order to establish the necessary clearance between the bearing and the journal. The thickness of the shims between the joints should be such that the clearance, or the difference between the diameter of the bore of the bearing and the diameter of the journal, is sufficient to permit the maintenance of an adequate film of lubricating oil between the bearing and the journal, but small enough to prevent pounding. Turning of the shells on the crankshaft during operation is prevented by doweling the top shell to the bearing cap or the lower shell to the seat in the bedplate. Compensation for wear of the bearing may be obtained by removing one or more shims from between the bearing halves.

22. The manner of mounting main-bearing shells described in the preceding article facilitates making repairs in case of wear. When it is desired to refit a worn bearing, the bearing cap is first removed; then, the bottom shell may be rolled out without disturbing the other bearings. Bearing shells are usually made of either forged or cast steel, although brass shells are still used in many instances for small engines. Brass shells have an advantage over steel shells in that they may be tinned more perfectly, thereby causing the babbitt to stick more tightly to the shell. Owing to the high first cost of brass shells they are rarely used except on small engines. In assembling a bearing on the journal, shims are placed between the bearing halves to provide the necessary clearance between the journal and the bearing.

23. Rebabbitting Worn Bearing.—When preparing a worn bearing for renewal of the babbitt lining, all old babbitt must first be removed from the shells. If the shells have dovetail grooves in which the babbitt is anchored, the shells should be heated in order to melt the babbitt out of the grooves. The shells are then cleaned and all traces of oil are removed by first washing them with gasoline and then rinsing with caustic soda. The inside surface of the shells is next tinned by first brushing with a solution of zinc chloride made by dropping pieces of zinc in a muriatic acid solution; then the surface is tinned with a stick of solder while the shells are heated with a blow torch. The two shells are next placed on end on a level surface. Paper or brass shims are put between the halves and then the shells are clamped together. A mandrel having a diameter slightly smaller than the diameter of the journal is placed in the center and the bottom edge of the assembled shells is surrounded with wet fireclay; then the molten babbitt is poured around the mandrel. The babbitt should be hot enough to char a pine splinter thrust into it but not so hot as to cause it to burst into flame. When the babbitt has solidified, the mandrel is withdrawn and the bearing is reamed to the exact size of the journal. The bearing halves are than separated and reassembled on the journal where they are scraped to a fit.

24. To fit, or *spot,* a bearing on a journal, the journal is given a coating of Prussian blue or lampblack. The bearing is then assembled on the journal and rotated about the journal a few degrees. After the bearing has been removed the high spots on the bearing surface will be indicated by the presence of blue marks on the inner surface of the bearing, and these marks must be scraped off carefully with a scraping tool. The journal is then again coated with Prussian blue and the fitting process is repeated. At the beginning of the scraping process the bearing may seat at only a few points, but continued scraping will finally result in a bearing being indicated all over, when it may be considered finished.

In large bearings the babbitt is frequently poured into the bearing shells by what is known as the centrifugal casting process. In this process a hollow steel cylinder of the same length as that of the bearing shell is first turned so as to fit a machined recess in the engine bed and in the bearing cap. This will form the shell of the bearing in which a suitable babbitt lining is then cast. The inside surface of the hollow cylinder is first tinned and the cylinder is then revolved at a high rate of speed while molten babbitt is poured into it. The cylinder continues to revolve until the babbitt has solidified. Because of the high rate of speed of the revolving cylinder the denser babbitt is thrown toward the cylinder walls and the less dense and more porous babbitt remains in the center, afterward being removed by boring out the shell to the required diameter. In this manner a sound babbitt lining free from air holes is produced. Grooves machined in the cylinder serve as anchors for the babbitt. The finished bearing is sawed lengthwise in halves and the joints are trued on a milling machine.

When centrifugal casting is employed in forming the bearing lining, the bearing may be reamed to the exact size of the crankpin or main journal, and very little scraping will be necessary to secure a good fit, as a reamed bearing will run itself in during a few hours of operation. Care should be taken, when reaming the bearing, to bolt both bearing halves together with the same tension as will exist when the engine is in operation. If this is not done, the bore may be distorted when the bearing bolts are drawn up during the assembly on the journal, causing the lining to crack. If such cracks are small, the trouble may be remedied by cutting out a portion of the lining containing the crack and replacing it with solder. However, if the cracks are large it is best to rebabbitt the bearing and refit it to the journal.

25. Composition of Bearing Lining.—Bearing linings may consist of alloys of copper with tin and lead; alloys of copper with cadmium, nickel, and silver; alloys of lead with tin and antimony; and alloys of tin with copper, antimony, and lead, the latter alloys being known as babbitts. Alloys of zinc with copper and aluminum are also sometimes used. The main object of using the various alloys mentioned is to reduce to a minimum the friction between the bearing and the journal for any particular condition of loading. The percentages of the metals in different lining compositions varies widely to suit different types of service and lubrication. Examples of babbitt compositions are: tin, 88.9 per cent, copper, 3.7 per cent, antimony, 7.4 per cent; or tin, 80 per cent, copper, 10 per cent, antimony, 10 per cent. These two compositions are known as soft babbitt and hard babbitt, respectively. Large engines subject to heavy loads often have a main-bearing lining of 70 per cent of copper and 30 per cent of lead. Bearing linings, or bearing bronzes, for piston pins are frequently composed of 80 per cent of copper, 10 per cent of tin, and from 0 to 10 per cent of lead; the remainder, if any, being phosphorus.

If the composition of the lining of a bearing is too soft, the metal may melt, or wipe, by the heat developed in the bearing during operation. When this happens the bearing clearance will be destroyed and the oil grooves in the bearing will fill up with the soft metal, causing the oil film to be squeezed out of the bearings with consequent harmful results.

26. Sources of Bearing Troubles.—Poorly fitted and poorly lubricated bearings are the main sources of trouble in engine operation. It is of the utmost importance that bearings are fitted on the journals with the proper amount of diametrical clearance, which is usually specified by the engine builder. Especially should bearings be accurately fitted in engines in which the bearings are subjected to very high pressures, such as is the case in Diesel engines, owing to the high compression pressures developed. As a general rule, the rate of wear of a bearing is dependent on several factors, including the quality of the lining material, the efficiency of lubrication, the number of hours of operation, etc. Rapid bearing wear will result when the bearing is subjected to greater loads than those for which it is designed. In a newly built engine, the bearings are usually adjusted for correct running before the engine leaves the shop, but a final bearing fit is acquired only after the engine has had a prolonged period of operation under load. It is therefore good practice to inspect bearings of a new engine frequently and carefully during the breaking-in period of the engine. After the engine has been broken in and it is reasonably safe to assume that a good running fit has been obtained in the bearings, they need not be inspected so frequently thereafter, as a well-lubricated and properly fitted bearing will give good service for a long period of time.

27. **Heating of Bearing.**—Heating of a bearing may be caused by the use of dirty or poor-grade lubricating oil, or by insufficient lubrication. Most bearing troubles can be prevented by keeping the oil in good condition, and by maintaining the correct pressure in the lubricating system. A hot bearing should be carefully watched, as it may cause the engine to become overloaded. Temporary relief may be obtained by increasing the flow of lubricating oil to the bearing, but at the earliest opportunity the bearing should be scraped to a fit. If the cylinder jackets leak water through defective packing, water may drip onto the bearings, causing rust to be formed in the bearings. The condition of the oil pipes that carry oil to the bearings should be inspected regularly to see that the pipes are not bent, crushed, or broken, or that they do not interfere in any way with the proper flow of lubricant to the bearings. If heating trouble develops in one of the main or crankpin bearings, causing the bearing to wipe, the oil holes in the crankshaft must be cleaned of any babbitt metal that may have run into them.

28. Heating of a bearing may also develop when the bearing does not possess sufficient bearing area, or area of contact between the bearing and the journal, to withstand the load to which the bearing is subjected. Hence, if the wear is excessive, the bearing area may be reduced to such an extent that heating will result. A hot bearing may also result when the bearing is not properly alined with the crankshaft, or when the bearing is set up too tight. The first thing to do in case a bearing runs hot is to increase the oil supply. At the same time the oil filter in the system should be examined to see if it is in good working condition, and the oil cooler should be checked to see that the oil is being cooled properly. Spraying of water on a bearing as an emergency measure is not to be recommended, because water may enter the lubricating system, or cause warping and cracking of the bearing because of unequal contraction of the parts. If

the bearing temperature continues to rise, there is great danger that the bearing shells, or brasses, will expand until they grip the journal, thereby increasing the friction between the journal and the bearing until the bearing becomes so hot that the lining will melt. The temperature of a bearing that runs hot may be reduced by slowing down the engine speed and thus decreasing the amount of work thrown on the bearings. Another remedy for a hot bearing is to loosen the nuts on the bearing bolts to a slight extent, but care must be taken not to loosen them too much, as in that case the bearing will pound. It is good practice to keep a record of the correct running temperature of each bearing of an engine; then the operator will be warned, by an undue rise in temperature of one of the bearings, that something is wrong with either the bearing itself or the lubrication of the bearing. A rise in temperature of the lubricating oil of one degree or more per minute is always a sign of danger, and the operator should in that case use his judgment whether to effect temporary means of relief or stop the engine at once.

29. Loose Bearings.—Heavy knocks, or pounds, in an engine are often caused by looseness due to wear in the main-shaft bearings, or the piston-pin bearing. Knocking due to a worn crankpin bearing may occur at slow speeds, as, for instance, when the engine is started up or comes to a stop, but at normal speeds the centrifugal force acting on the connect-rod overcomes the tendency to knock, even though the crankpin bearing should be somewhat loose. In a vertical engine the main bearings may be somewhat loose without causing a knock, because the weight of the shaft and flywheels holds the shaft down, but a horizontal engine will, under certain conditions of speed and load, pound with a small amount of looseness. Only a very limited amount of looseness should be permitted in the main bearings of any engine, both on account of the danger of springing the shaft and because a bearing worn beyond this extent is liable to begin cutting, as it is difficult to keep sufficient oil in it. As a general rule, bearing knocks that develop gradually and do not increase in intensity are due to wear of the bearing and are not immediately dangerous. At the earliest instant possible, however, such wear should be remedied, as excessive oil consumption may result in the bearing. If bearing knocks develop suddenly and increase rapidly in intensity, it is best to stop the engine at once and investigate the trouble. Most likely it will be found that one or more of the nuts of the bearing bolts have become loose, or a bearing bolt may be broken. If it is assured that the knock is a result of bearing wear, the trouble may usually be eased temporarily by increasing the pressure in the force-feed lubricating system, thereby causing the bearing clearance to become filled with oil. This cushions the blows that might otherwise cause the lining of the bearing to become loosened from the shells.

30. Excessive main-bearing clearance can be detected by taking lead impressions, or an approximation of the clearance may be obtained by the use of feelers. When taking lead impressions, the upper half of the bearing is first removed and three lengths of lead wire, $\frac{1}{16}$ inch or $\frac{1}{32}$ inch in diameter, are laid across the top of the journal, one near each end and one in the center of the journal. If the journal is very long, four pieces of lead wire may be required. The pieces should be long enough to extend from edge to edge of the bearing surface. The upper bearing half is then replaced and the bearing-bolt nuts are set up tight, care being taken to mark the position of each nut. Next, the upper bearing half is removed and the thickness of the squeezed lead wires is measured with a micrometer. This thickness, which is equal to the clearance, should conform to the clearance specified by the engine manufacturer. If the leads are of uniform thickness throughout their lengths, the box will bear evenly over its surface, but if they are thinner in some places than in others, there are high spots in the babbitt that must be scraped down. It is also important to check for uniformity in clearance along the entire length of the journal, which is indicated by identical thickness of all three lead wires. If the clearance is not uniform, only a portion of the bearing surface will carry the entire load on the bearing, and thus cause the bearing to run hot. After the leads have been removed, the upper bearing half is again fastened to the lower half, the nuts on the bearing bolts being drawn up to the same position as marked before. This fastening insures that the tension on the bolts will be the same as when the leads were in place on the journal.

The clearance between the journal and the bearing should always be measured with the bearing bolts set up tight and the amount so found should agree with the engine builder's specifications. Adjustment of the clearance is made by varying the thickness of the shims between the butting joint surfaces of the bearing shells. In large bearings the babbitt is sometimes chamfered, or relieved, at the joints of the bearing so as to allow a slightly larger clearance at the sides. This clearance prevents the shells from gripping the journal if the bearing runs warm and assists in spreading the lubricating oil around the journal. It has been general practice to adjust main and connecting-rod bearings for a clearance of .001 inch per inch of diameter of the journal, but in modern high-speed engines the amount of bearing clearance is often made smaller than this. Large bearing clearance in such engines is not only unnecessary, but is frequently harmful, as it allows the lubricating oil to run out of the ends of the bearings.

31. Causes of Loose Bearings.—Looseness of either main or connecting-rod bearings may be the result of wear due to long service, or it may be caused by one or more of the following conditions.

1. Derangement of the oiling system, resulting in an insufficient supply of oil to the bearing surfaces. Insufficient lubrication produces premature wear and looseness of the bearings.
2. Misalinement of bearings, as a result of a bent connecting-rod or a sprung crankshaft.
3. Insufficient lubrication due to a dilution of the oil. The cause of this may be improper carburetion or a poor fuel, or the running of the engine for too long a time without changing the oil in the crankcase.
4. Incorrect lubrication caused by using an unsuitable kind of lubricant.

5. Bearings incorrectly fitted at the factory, or when last adjusted or replaced.

32. General Symptoms of Loose Bearings.—When a bearing is loose, two symptoms are present, either one of which may help the operator in diagnosing any possible trouble in the bearing assembly. The first of these symptoms will be developed only in engines using the hollow crankshaft pressure-lubrication system, in which a loose bearing is indicated either by a falling-off in the reading of the oil-pressure gage or by an excessive oil consumption. The effect of a fall in the pressure of the lubricating oil will be felt first by those bearings at the highest points of the lubricating system, such as the piston-pin bearings or cam-shaft bearings.

The second symptom, which is developed in all kinds of engine oiling systems, is the presence of abnormal noise in the engine. A noise of this kind can be produced only by an engine that has been running for some time with loose bearings; it has, consequently, passed beyond the period in which loose bearings would be indicated by a lower reading of the pressure gage or by a high oil consumption.

33. A low reading of the oil pressure gage may indicate looseness of the bearings, or a derangement of the oil pump or of the pressure release valve. If the bearing halves are separated by shims, and the shims are not properly fitted, it is quite possible for the lubricating oil to leak out of the ends of the bearing. A common source of trouble, especially in lower connecting-rod bearings, is that the lengthwise oil groove in the upper crankpin box is made too long, so that the ends of the groove are too close to the ends of the bearing. When this is the case, the oil, instead of being spread evenly over the entire surface of the journal, follows the path of least resistance and flows out of the ends of the bearing.

34. Checking Main Bearings for Wear.—In stationary engines the final fitting of the main bearings is carried out in the shop during the erection of the engine. This is done as follows: After the bottom halves of all main bearings have been mounted in the cross-partitions of the bed, or frame, of the engine, the boxes are accurately alined so that an imaginary center line of the crankshaft passes through the exact center of each bearing. Then the crankshaft is lowered onto the bottom bearing halves and a bridge gage is placed over each journal. The gage rests on smooth level surfaces machined on the engine frame and is provided with a projecting lug directly over the top of the journal. By measuring the distance between the top of each journal and the lug on the gage, the true position of the crankshaft is determined. A record is kept of these measurements and each measurement is usually stamped on the engine frame near the bearing for which it is intended. Any subsequent deviation from these readings will indicate how much the crankshaft is above or below its true position and represents a certain amount of wear in the main bearings. As the wear is practically always in the bottom shells, the remedy for a dropped crankshaft is to replace or rebabbitt the affected bottom shells. In some engines, the bearings are made adjustable so that the wear in each bearing can be taken up by means of a wedge underneath the bottom shell. In this way the position of the bottom shell may be adjusted by turning a long screw fastened to the wedge and extending through the engine frame.

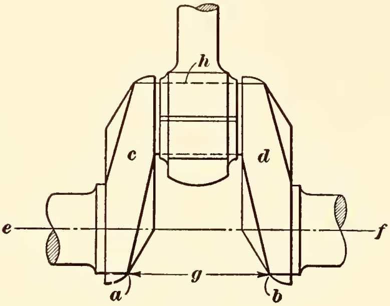


Fig. 5

35. Test for High or Low Main Bearing.—Another method that may be conveniently used when it is desired to check whether any of the main bearings of a crankshaft is high or low is to measure for each crank the distance between two fixed points, such as *a* and *b*, Fig. 5, on the crank webs *c* and *d*, as far removed from the center line *ef* of the crankshaft as possible. This measurement *g* should be accurately determined at four positions of the crankpin *h*; that is, with the pin on the top center, front horizontal center, bottom center, and rear horizontal center. It is best to employ a very sensitive precision instrument, such as a dial indicator or a micrometer, to measure the distance *g*. If either of the main bearings adjacent to the crankpin *h* is high or low, the center line *ef* of the crankshaft will no longer be a true straight line but will be distorted. Then, when the crank revolves about this distorted center line, the distance *g* will not be equal for all four positions of the pin *h*.

The advantage of the method here described is that the readings may be taken when the engine is at rest, without dismantling or disturbing any of the main bearings. As a general rule, crankweb deflections in internal-combustion engines should be limited to plus or minus .00025 inch in engines having a stroke up to and including 11 inches, and to plus or minus .0005 inch in engines having a stroke of more than 11 inches.

36. Looseness in the flywheel bearing of a vertical motor is disclosed by putting a jack under the flywheel and working it gently up and down. In the case of a horizontal engine it is necessary to move the shaft approximately in line with the pressure of the explosions, and a lever will have to be applied to the flywheel or shaft in whatever manner seems most practicable. Occasionally, looseness of the shaft can be detected by rocking the flywheel back and forth against the compression in the cylinder. A novice should not attempt to refit the main-shaft bearings, as it requires a good deal of skill and experience to do this correctly.

37. In an automotive-type gas engine, loose main bearings are always loudest under a load or pull. In tone a main-bearing knock might be classed as a dull pound, or thud. Loose main bearings, unless the condition is very bad, will not be audible when the engine is idling, except when the engine is not firing evenly. The noises may usually be diminished slightly by retarding the spark. The above symptoms apply to a main bearing that is only slightly loose. If the bearing is unusually loose it will be manifested not only by a decided dull pound, but also by vibration of the engine when it is steadily accelerated.

The sound from loose main bearings can be diminished by shorting out the cylinders. To determine what particular bearing is loose requires no little skill, and a knowledge of the number of main bearings used in the construction of the particular engine is of considerable help. If the engine crankshaft, for instance, is carried on three main bearings the method is as follows:

Start the engine and increase the load sufficiently to make the engine labor. Then, short out cylinders No. 1 and No. 2, to locate a noisy front main bearing. This may be done by making contact between each sparkplug and the engine by means of a screwdriver or any metal strip. Shorting out No. 3 and No. 4 will locate a loose center main bearing, and No. 5 and No. 6, a loose rear main bearing. When shorting out main-bearing knocks always do so on two cylinders at a time, one on each side of the main bearing and nearest to it.

If a main bearing is badly pounded, burned, or worn, it will be audible at all conditions of running, whether the engine is pulling or otherwise. The center bearing of a three-bearing shaft is usually the one to show a knock first.

38. Testing for Loose Bearings.—In small engines a loose lower connecting-rod bearing may be located, after the engine has been stopped, by jumping the connecting-rod and piston with a bar, but in large engines this method is not practicable and in such engines the bearing clearances should be measured by the use of lead wires as explained before. The most direct method for determining the condition of bearings oiled by pressure lubrication is to subject them to conditions similar to the ordinary working condition and then watch the results. An imitation of the working condition may be obtained by disconnecting the regular engine oil pump and forcing the oil through the lubrication circuit by means of a pressure derived from an independent source. This test is based on the fact that a bearing with a contact surface equal to or in excess of 75 per cent of the total bearing area will permit very little oil to pass along the bearing surface. In bearings working with pressure lubrication, it is possible to locate in this way a connecting-rod bearing without any visible looseness, when forced up and down on its crankpin; likewise, a shaft may be tested in a similar manner and found loose without showing any looseness of its journals when tested in other ways. These bearings may allow the oil to pass freely over their surfaces. This condition is generally due to poor contact of the babbitt metal, or to a faulty condition of the shims, the connecting-rod, or the cap.

39. **Testing Bearings in Small Engines.**—On engines provided with a splash-lubrication system, loose connecting-rod bearings may be detected by grasping one by one the ends of the rods and shaking them up and down. On the main bearings it will be possible to detect any looseness by placing a jack under the flywheel at a point adjacent to the bearing suspected of being loose. As soon as the upward pressure is sufficient to raise the shaft, any looseness will be evident by the visible contact established between the journal and its upper bearing half.

40. **Methods of Repairing Loose Bearings.**—After the loose bearing has been located, there are three methods by which the trouble may be eliminated, depending on its nature and its duration. The methods are as follows:

1. Tightening or adjusting the bearings.
2. Refitting the bearings.
3. Installing new bearings.

41. **Tightening Bearings.**—The first remedy that is most generally applied to an engine with loose bearings is to tighten them or by other means bring the bearing halves closer together, or to snug them up, as the saying is. This may be done, either by removing the bearing caps and taking out one or more shims from each side, or by reducing the depth of the bearing caps by machining or filing and reassembling the bearings. This method of adjusting is practicable only in cases where the bearing metal as well as the journals are in good condition.

42. Refitting Bearings.—In cases where a bearing was allowed to run loose for some time, it will usually be found necessary to refit the bearing in addition to the snugging-up operation just referred to. The refitting consists of removing the bearing cap, observing the amount of contact, or spotting, on the babbitt lining, and then by rescraping or reaming the bearing halves so as to secure a surface contact equivalent to 75 per cent or more of the total contact area.

43. Installing New Bearings.—It will be necessary to install new bearings, when one or more have been pounded or burned out, as a result of misalinement, faulty lubrication, or from other causes. To renew a connecting-rod bearing, the old bearing shells or bushing halves must first be removed. In case of automotive-type gas engines, in which the lower connecting-rod bearings have the bearing metal cast in place, it will be necessary to procure a new rod or have the old one rebabbitted. If the main bearing is burned out, it will be necessary to remove the crankshaft from the engine, and install new bearing shells. In engines equipped with interchangeable bushings, it is possible to install new bushings by slightly lowering the crankshaft and installing the bushing halves without a previous scraping or reaming.

44. Adjustment of Crankpin Bearings.—The connecting-rod bearings wear more quickly than the main crankshaft bearings owing to the greater unit stress to which they are subjected, and it may be necessary to take these up. To judge the amount of looseness of the bearings, the piston and connecting-rod should be "jumped" with a bar. If there is only slight wear between the bearing and its journal, this can be taken up by removing one or more of the thin shims, or liners, ordinarily used to separate the bearing caps from the seat. In many cases laminated shims are provided by the manufacturer, several layers of shims being pressed together, so that one layer at a time may be peeled off. The thickness of each layer is usually .003 inch. Care must be taken to remove an even number of shims of equal thickness from each side of the bearing. The shims may be made of copper, brass, or paper.

and are usually held in place by dowels in such a way that they may be removed without removing the bearing bolts. If no shims are provided, or if all the shims have been removed from each side of the bearing, the sides of the bearing must be filed or planed down to provide clearance and shims should be installed when replacing the bearing. If there is considerable looseness after one or two shims have been removed from each side, or if the crankpins or their bearings are cut and scored, it is advisable to scrape the bearing to a fit before the bearing cap is tightened up. Before this is done, however, the crankpins must be smoothed up and tested for roundness. In case they are out of round they must be trued up carefully, as otherwise the bearing will soon wear loose again, the result being a noisy engine. If the crankpin is true but scratched or marked, it should first be filed carefully with a very fine file and then smoothed and polished by means of a lapping tool such as is shown in Fig. 6. Two pieces of hard wood, of a width equal to about one-half the length of the pin, are drilled and bolted together, and a hole *a* is bored to the size of the pin. An abrasive paste composed of fine powdered emery and oil is placed in the lap, and the blocks are then clamped to the crankpin. A side-to-side and rotary movement is then given to the lap, and new abrasive added from time to time until the desired polished surface is obtained; the pin must then be cleaned of all abrasive with gasoline.

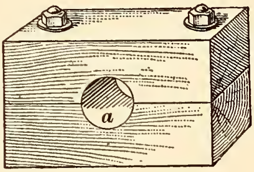


Fig. 6

After the crankpins have been trued, polished, and cleaned, the connecting-rod bearings must be fitted to the pins. To insure a good fit of the bearings, they must be scraped, and while this scraping is a tedious operation, a good job can be done with a certain amount of care and patience. The brasses must have about $\frac{1}{64}$ inch end play, and must not bear on the rounded corner or fillet at the ends of the crankpins. The normal value of the clearance for a crankpin bearing is .001 inch per inch of crankpin diameter. This clearance, however, depends largely on the method of lubrication employed and may also vary in different engines depending on the pressures to which the crankpins are subjected, the engine speed, etc.

45. Assembling Crankpin Bearings.—In replacing the bearings, the nuts must be drawn up tight and shims must be used to obtain the correct adjustment. The bearings must fit loosely to prevent heating; at the same time they must not be slack or the engine will pound. The oil film is maintained in the bearings by forcing a relatively large amount of oil through the bearings under high pressure. The higher the pressure of the oil, the looser the bearings can be. Newly scraped bearings must be adjusted closer than old ones that are already worn smooth, as the shaft will touch the bearings in only comparatively small spots, and these spots will wear very quickly until the bearing is worn to a fit.

46. It is generally possible to determine by means of the sounds produced at various engine speeds whether the source is in the connecting-rod bearings or the main bearings. For instance, a loose connecting-rod bearing will produce its maximum sound when the engine is running light or when it is accelerating. Unless the bearings are exceptionally loose, the connecting-rod will emit a sharp, tapping sound at idling speeds. This sound may periodically come and go at these speeds and may be confused with a loose piston pin. But in the latter case the noise will be at its maximum immediately after the engine begins to accelerate. In tone, a loose lower connecting-rod bearing is something similar to a light pound, while on certain engines it is manifested as a clatter or series of short raps. The tone is always sharper than the main-bearing dull knock and on the average high-speed type of engine with pressure lubrication, unless the bearing is burned out, never gets louder than a light rap or a series of raps. If badly worn or burned, the lower connecting-rod bearings will be audible under all conditions of running.

47. A loose lower connecting-rod bearing in a vertical engine may be detected by prying the crankpin box up and down with a bar, the edge of the frame door being used as a fulcrum, or by setting the crank at about half stroke and rocking the shaft back and forth. In automotive-type engines, loose connecting-rod bearings may be detected by shorting out each cylinder in turn. A so-called trouble-finding pump may also be used for detecting loose lower connecting-rod bearings. These pumps may be purchased with a pressure gage attached, or they may be made up from a single-acting tire pump or a grease gun. Before using the pump it should be first definitely ascertained that the noise is not caused by a loose piston. This may be done by testing each cylinder with a pressure gage to check whether the same compression exists in all cylinders. If the pressure-gage reading for each cylinder is within 10 pounds of the standard for the engine, the noise is not likely due to a loose piston. The procedure, then, for locating the loose connecting-rod bearing that is responsible for the noise consists in first removing all of the sparkplugs, or, if the pump is equipped with the proper fitting, by removing the priming cocks. Screw the end of the pump into the sparkplug or the priming-cock hole, as shown at *a*, Fig. 7, and with the piston of the cylinder near the top center position, with both valves closed, create a vacuum in the cylinder by pulling out

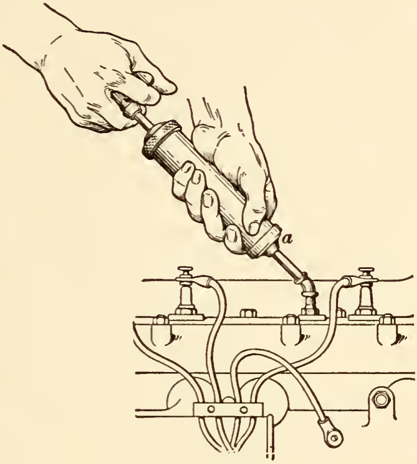


FIG. 7

on the pump plunger. If pushing in and out on the pump plunger produces a noise, it indicates either a loose piston pin, or connecting-rod lower bearing. In this way the source of noise is brought down to two possible locations. The operator then should determine by means of other tests, as described in a later article, whether the piston pin for that cylinder is worn badly or not. If not, it may be safely assumed that the crankpin bearing is responsible for the noise. It is, of course, necessary with the pump test that the valves be closed at the time and also that they be free from leakage, as the success of the pump test depends almost entirely on the forming of a vacuum in the cylinder above the piston, a condition impossible to obtain with badly leaking rings or leaky valves.

48. Piston-Pin Bearings.—The piston-pin end of the connecting-rod is usually provided with a bronze bushing which serves as a bearing for the piston pin. The bushing is not adjustable, mainly for the reason that the wear of the bronze is so small that the bushing has to be replaced only after a long period of operation. In addition, bronze withstands the high temperature to which the piston pin is subjected, because of the heat absorbed from the piston, much better than would a two-piece bearing lined with babbitt. Generally the bushing is pressed into the upper end of the connecting-rod and then doweled in place. New bushings are scraped to fit the piston pins. Care should be taken in installing a piston-pin bearing that the side clearances between the connecting-rod and the piston bosses are as specified by the manufacturer. The rotation of the piston pin may be confined to the piston bosses, the pin being held in the rod bushing by a setscrew or other means; or, the pin may be held in the piston bosses by setscrews and be free in the rod bushing, or the pin may turn in the piston bosses as well as in the bushing, in which case the pin is said to be full-floating. Side motion of a full-floating piston pin may be prevented by two aluminum caps fitted in the piston walls against the ends of the pin, or by spring clips mounted between the rod and the piston bosses and provided with bent ends that slip into grooves in the piston pin. If the pin is held from turning in the piston bosses by setscrews, the screws also prevent any side motion of the pin, thereby avoiding possible damage to the walls of the cylinder.

49. Knocking in the piston-pin bearing, due to wear of the pin and its bushing, should not be neglected too long, as the bushing and the pin will soon be worn out of round, so that they cannot be used. The amount of play can be gaged in the following manner: The crank is first placed on the bottom center and a short block is placed on top of one of the crankpin-bearing bolts. Another block is placed on top of the first block reaching to the bottom of the piston, then a bar is inserted between the two blocks, and the two blocks are pried apart. By moving the piston up and down in this way, the play in the piston-pin bearing may be felt at the bottom edge of the piston with the fingers. When excessive slack is found in the bearing, the piston pin should be removed and calipered all around. If it is out of round, it should be ground true; or, if this is impracticable, a new oversize pin will have to be supplied, and the bushing reamed or scraped to fit. When the pin has its bearings in the piston and is held rigidly in the small end of the connecting-rod, the holes in the piston are usually not bushed. Hence, when there is excessive wear between the pin and piston, the best repair is to install both a new piston and pin. The holes in the piston may, however, be reamed out to a greater diameter and an oversize pin fitted, in which case the connecting-rod bearing necessarily must be reamed also. If the oversize pin cannot be obtained from the manufacturer it can be made in a machine shop. Machinery steel should be used case-hardened to a depth of about $\frac{1}{8}$ inch, and then ground. Usually the use of a new piston and pin will be cheaper. In assembling connecting-rod bearings the piston-pin bearing should be carefully put together so that the oil hole will be in the correct position.

A hot piston-pin bearing may cause the pin to elongate, and, when the pin is held in bosses in the piston wall, as is sometimes the case, this may cause the walls of the piston to be pressed outward. In turn, this causes the piston to run hot and stick in the cylinder, and in bad cases the ends of the pin may score the cylinder walls.

50. In automotive-type engines, abnormal engine noises produced by loose piston pins are always loudest when idling. They are usually less audible with the spark retarded than when advanced. In tone the noise from loose piston pins is usually a sharp, metallic knock.

It is easy to confuse a piston-pin knock with a connecting-rod lower-bearing knock, especially when the pins are badly worn or loose. There are several methods for detecting loose piston pins as follows:

1. Use the trouble finder's pump, as outlined in Art. 47.
2. With the engine idling slowly, hold open with the screwdriver the exhaust valve of the suspected cylinder. This can be easily accomplished by inserting the point of the screwdriver between the exhaust-valve stem and the top of the tappet screw, and prying up or down so as to raise the valve fully off its seat. Relieving the compression in this manner will eliminate the knock unless the pin is unusually loose, and even then it will noticeably diminish the sound.
3. The third method consists in idling the engine and shorting each plug in turn. When a certain cylinder is suspected, place the screwdriver against the upper part of the cylinder and the other end to the ear. Then remove the screwdriver from the cylinder and place the end on the crankcase. If a loose piston pin is causing the knock, the noise will be much louder and more distinct when the screwdriver is against the cylinder. If the noise is louder when the screwdriver is held against the crankcase, it indicates a loose lower connecting-rod bearing.

51. In stationary engines, knocking is occasionally found to be due to the piston pin and the crankpin not being quite parallel. This causes the connecting-rod to oscillate from end to end of the piston pin and crankpin bearings; and if, as is customary, there is end movement in these bearings, the knocking may be quite noticeable. If it should be impossible to make the pins parallel, the only recourse is to take up the lost motion at the end of one or the other bearings, and possibly both bearings, by the use of washers or cheeks soldered to one end of the bushing and brasses.

INSPECTING AND FITTING BEARINGS

52. Inspection of Bearing and Crankpin.—The crankpin should be thoroughly examined to see that it is smooth and circular. If any ridges and cuts are found on its face, no attempt should be made to adjust the bearing until the crankpin is reconditioned. In pressure-lubricated engines a ridge will generally be found all around the crankpins, directly in line with the oil hole in the pin. This ridge does no harm, provided the bushing halves in the cap and in the rod have corresponding grooves. Any other ridges or cuts on the face of the pin should be corrected, as they prevent a full bearing contact.

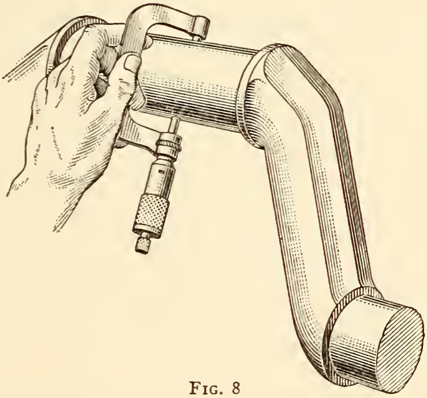


Fig. 8

The crankpin may appear smooth and yet be eccentric and tapered. Hence, before beginning any adjustment, it is always advisable to test the crankpin with a micrometer. The test should be made at four points along a circular path, this test being repeated at three places along the pin. That is, in all, twelve measurements are taken in the manner shown in Fig. 8.

53. Inspection of Babbitt Facings.—The babbitt facings in the bushing halves fitted into the end of the connecting-rod and into the end of the cap should have contact surfaces of a uniform light-gray color. Bright spots found anywhere on the babbitt surface indicate that there has been direct contact between the pin and the bushing, the bearing being clamped too tight to the pin. A bearing cannot be satisfactorily adjusted unless the bushing halves have a contact area amounting to at least 75 per cent of the pin area. The extent of the contact area may be estimated from the area of the gray-colored facing. For this reason it is unnecessary to blue a bearing to test its contact area, except in the case of new bearings.

Provided that the bearing contact surface is circular and concentric with the pin or with the journal and that there is a correct diametral clearance, the pin will, so to say, float on a film of oil. Under these conditions the babbitt face will assume the dull, gray color associated with a perfect contact surface. Only in cases where the clearance is insufficient will the babbitt appear bright and polished. On the other hand, if the clearance is too great and the contact surface uneven, it will be impossible to maintain an oil film of uniform thickness. The babbitt facing will then assume a dark brown or a blackish color. If the babbitt facing of each crankpin bearing does not comply with the standard mentioned, it will be useless to attempt any adjustment before these parts have been made to comply with the requirements.

54. Fitting Shimless Connecting-Rods.—Shimless connecting-rod bearings are found on many small pressure-lubricated engines. The manufacturers of such engines usually advise against adjusting the bearings, preferring that the rod be returned to them for renewal. The new connecting-rod is generally machined to fit the pin, so that little additional fitting will be necessary. However, in cases of emergency it will be necessary for the operator to know how to make an adjustment.

The purpose of this adjustment is to bring the cap closer to the pin by removing the metal from the parting faces of the cap. As it is important to know the depth of the layer to be removed, the first step in the procedure is to measure the thickness of the cap flanges with a micrometer, as in Fig. 9. This illustration shows the babbitt lining *a* cast into the cap. After the thickness is measured, it is reduced by placing the cap on a piece of emery cloth, tightly stretched over a surface plate or over a piece of glass, and rubbing the parting faces until the flanges have been reduced to the required thickness. The cap with its shell must be held securely during the rubbing process and must be raised periodically after one minute's rubbing to have the flanges tested with a micrometer.

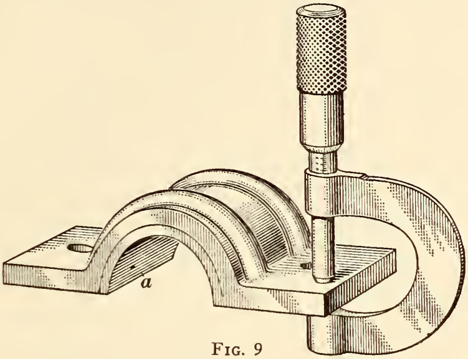


Fig. 9

55. When a bearing cap is adjusted by means of the rubbing process just described, it is not advisable to remove more than a .003-inch layer from the bearing cap, as a greater reduction will tend to throw the bearing out of round and thus prevent a uniform contact with the crankpin. In such cases the incomplete contact can be restored only by refitting the bearing with a scraper or a reamer. Hence, the aim should be not to remove any more than .002 inch at the first lapping operation, and then fasten the cap to the rod by means of the bolts and nuts. After the cap is securely fastened, the condition of the joint at the parting line between the cap and the rod should be carefully examined. When a perfect joint is looked at from either side, it should at no point be possible to see daylight between the cap and the rod. It should always be the aim to produce a joint of this standard for every rod that is to be adjusted, as a less perfect joint will allow too much oil to leak out from the bearing.

56. Testing the Fit of Connecting-Rod Bearing.—The following test may be made on automotive-type engines to test the fit of the connecting-rod bearings. After a satisfactory joint of the parting faces has been secured, the bearing cap is removed and the rod and the cap are attached to the crankpin. The test is made from below the engine and without replacing the piston in the cylinder. For the purpose of testing the diametrical clearance, it will be necessary to insert a liner of suitable material between the cap and the pin.

Laminated shim stock varying in thickness from .001 to .0015 inch or thin tissue paper may be used.

For an ordinary pressure-lubricated connecting-rod bearing, the diametrical clearance should be from .0015 to .002 inch. The method by which this amount of clearance is obtained consists in folding a leaf of tissue paper lengthwise, the double thickness obtained being very nearly equal to .002 inch. After the connecting-rod *a* is placed on the pin *b* in the position indicated in Fig. 10, the folded paper *c* is laid on the pin as shown, care being taken that the paper is without wrinkles and does not project at either end beyond the pin. Then the cap with its bolts and nuts is replaced and the bolts drawn up as tight as possible.

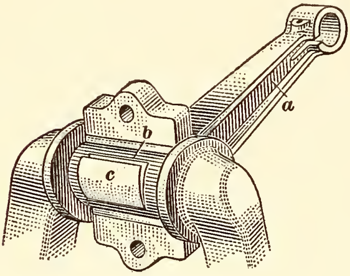


Fig. 10

57. The rod-and-piston assembly is now turned into a horizontal position; if it remains there without being supported in any manner, the bearing has the required clearance. While one hand is supporting the small end of the connecting-rod, the crankshaft is revolved once to see if there is any variation in the frictional resistance of the bearing. The cap is now taken off, the tissue paper removed, and the cap replaced. If, after the nuts are retightened, the assembly is able to turn freely on the pin and drop of its own account, when placed horizontally, a correct clearance is indicated.

58. Adjustment of Shimmed Connecting-Rod Bearings. The majority of engine connecting-rod bearings are equipped with some form of liner or with shims. These shims have the following functions to perform:

1. To restore a connecting-rod bearing to its original circular form. Most bearings are cast solid and afterward cut in halves. Shims are inserted at these parting faces to fill up the space left by the cutter and thus restore the bore to its original cylindrical shape.

2. To provide a means of adjusting the bearing for wear. The removal of one or more shims is one method of doing this.

3. Frequently shims are designed to seal the ends of the bearing where pressure-lubrication is used. The oil seal may be obtained by making the shims with tips that extend very close to the journals of the crankshaft. This is shown in Fig. 11 in which *a* represents the tips on the shims *b* placed on the joint surfaces of the shell *c*.

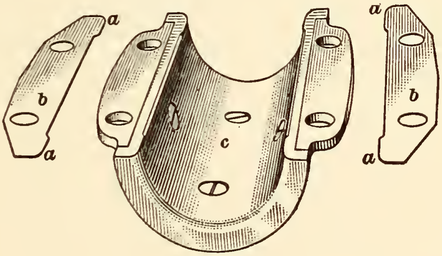


FIG. 11

59. In refitting new shims to an old bearing, all shims should first be removed from one side. After the thickness of these shims has been measured by means of a micrometer, they are replaced by new shims of the same thickness. The other side of the bearing is refitted in the same manner.

The next step is to adjust the tips of the shims in the manner shown in Fig. 12, which shows a crankshaft *a* with the connecting-rod *b* assembled and another connecting-rod *c* held against the crankpin *d*. The exact distance between the tip of the shim and the crankpin is now tested by means of a feeler gage *e*, the thickness of this gage not to exceed .002 inch. Although this test is shown as being made with the crankshaft removed from the engine, it can be made with the shaft in place, in which case it is advisable, while the test is proceeding, to replace the nuts for the purpose of preventing the bolts from falling to the floor.

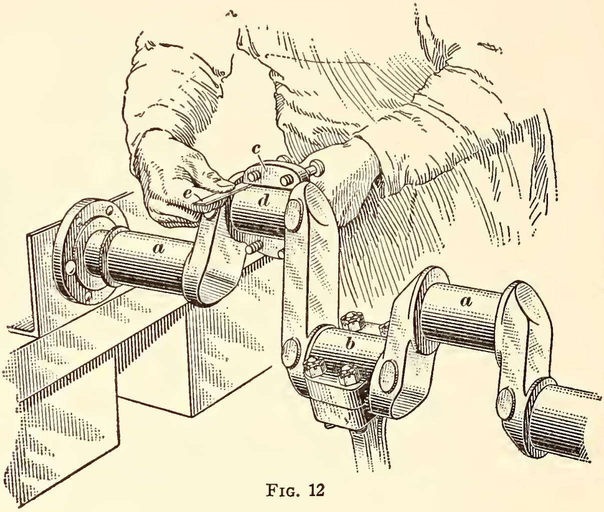


FIG. 12

After the connecting-rod bearing has been fitted on the crankpin in the manner described in Art. 56, the parting faces should first be tested for squareness by standing the rod on a surface plate and noting whether it will rock when pressure is exerted in a downward direction. The cap should be tested in a similar manner. Then the connecting-rod should be checked to see whether it is square with the crankpin and the piston pin.

60. The test for determining whether the connecting-rod is square with the piston pin and the crankpin is best made with the rod disconnected from the engine and placed in an upright position on a level surface such as shown at *a*, Fig. 13 (*a*). First the rod is checked to see whether it is square with the piston pin. A mandrel *b* machined and ground to the exact diameter of the piston pin is inserted in the piston-pin bearing of the rod. A stand *c* having a dial gage *d* attached to its upper end is placed on the surface *a*. The dial gage is next adjusted on the stand in such a way that the pointer of the gage bears against the lowest point of one end of the mandrel *b* with a light pressure; then, the reading of the gage is carefully noted. If the mandrel is square with the connecting-rod, the gage reading should be exactly the same when the pointer of the gage is placed underneath the opposite end of the mandrel. To determine whether the rod is also square with the crankpin, the cap *e*, view (*b*), of the crankpin bearing is placed on the level surface *a* and a mandrel *f* the exact size of the crankpin is placed in the cap. The machined joint surfaces of the cap should be supported on blocks as shown so that they are exactly level and at the same distance from the table surface. This may be checked by running a pointer of a dial

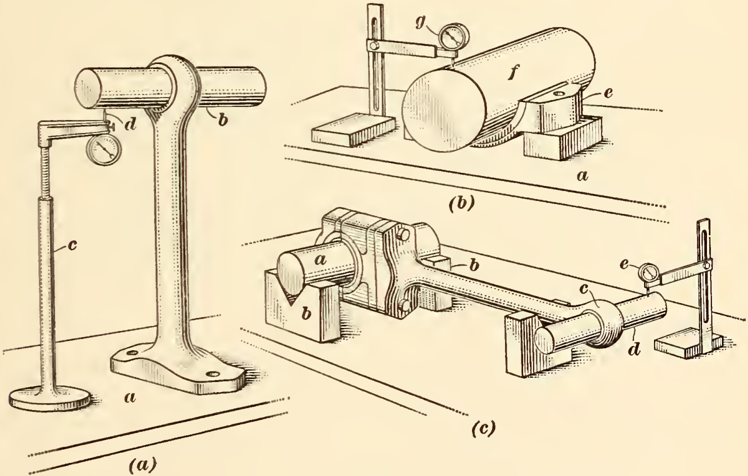
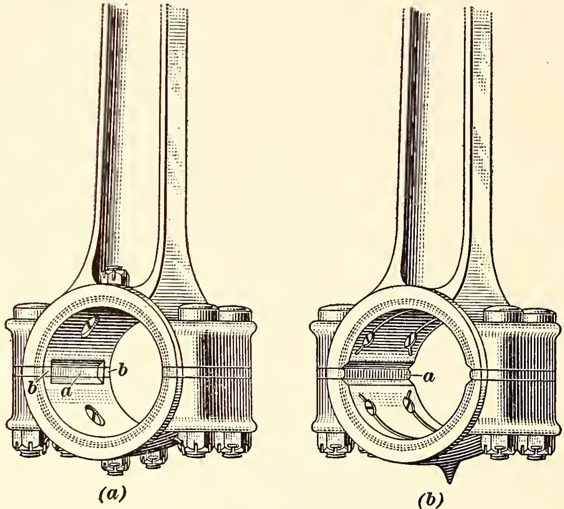


FIG. 13

gage over the machined surfaces. Next, the pointer of a dial gage *g* is moved along the top of the mandrel, and if the reading of the gage is the same at both ends the crankpin is square with the rod. After it has been determined that the pins are square with the rod, it may still be possible that the rod is twisted so that the pins do not lie in the same plane. To check this the rod is placed on a surface table as shown in view (*c*), with one mandrel *a* supported on two steel blocks *b* of exactly equal height. The end *c* of the rod is supported on a block as shown. Then, the distances from both ends of the mandrel *d* to the surface table, as measured with a dial gage *e*, should be identical.

The test for squareness of the connecting-rod with respect to the piston pin and the crankpin is important, because, if the test shows that the rod is not square with the pins, excessive wear of the piston pin will result. Also, the engine is liable to pound if the crankpin bearing strikes the crank throws, should the bearing move back and forth across the crankpin. After having made sure that all oil holes and oil grooves are free from any obstructions, the rod and the cap are fastened to the crankshaft and the final diametrical adjustment is given them.



(*a*) (*b*)

Fig. 14

61. Two connecting-rod bearings, of which one is arranged for pressure lubrication and the other for splash lubrication, are shown in Fig. 14. The bearing in view (*a*) is lubricated by pressure as shown by the relief *a* in the parting faces, which does not extend clear across, but is bounded at each end by the shim tips *b*, each of which is about $\frac{1}{4}$ inch long. In the case of the bearing arranged for splash lubrication, shown in view (*b*), the relief *a* extends all the way across the bearing and is provided with beveled edges.

On splash-lubricated engines the crankpin and the babbitt facings should be in the same condition as outlined in Arts. 54 and 55 with reference to adjustment of the shimless and of the shimmed types intended for pressure lubrication. Provided the bushings and the pins are in good condition, the bearings should be so adjusted that the connecting-rod will offer only a small frictional resistance to being turned after the bolts and the nuts are set up as tight as possible. A pull of about 2 pounds, applied through the intervention of a spring scale to the piston end of the connecting-rod, should be sufficient to start the rod, after which it should be possible to move the rod around the crankpin by pushing the end lightly with the fingers. In case the piston is attached to the rod at the time of adjustment, the proper tension will have been secured if the piston assembly will nearly fall of its own accord, when started with the fingers.

62. General Rules for Fitting All Types of Lower Connecting-Rod Bearings.—A rule applicable to all types of lower connecting-rod bearings is that old bearings should not be so tightly adjusted or fitted, as would new ones.

This is because bearings that have been run in are fully seated and, therefore, allowance need not be made for the final setting or wearing-in required by new bearings. The latter must be given less diametrical clearance to compensate for the final setting or wearing-in, which takes place in every new bearing. Lower connecting-rod bearings that have been reamed in line must be given a greater diametrical clearance than hand-scraped bearings, because the reaming operation gives a better contact and consequently approximates more nearly a run-in bearing. These general rules do not apply to refitted or to new bearings.

63. Conditions Requiring New Bearings or Refitting of Old Bearings.—In the preceding descriptions dealing with methods of fitting bearings, it was assumed that the crankpin, as well as the babbitt surfaces of the bushing halves, were in good condition. It is often found, however, that the babbitt surfaces of the bushing halves are either roughened or slightly burned, or offer insufficient contact, in which cases it is necessary to refit the bearing.

As the job of reconditioning crankpins has already been described, it will be assumed that the pin is in good condition and that the job in hand is to refit the old babbitt surfaces to the crankpin. Possibly, one or more of the rod bearings are so badly burned or roughened that refitting is impossible, in which case new connecting-rod bearings must be procured.

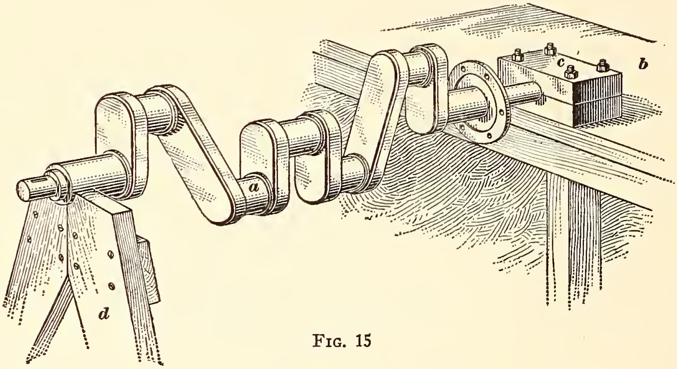


Fig. 15

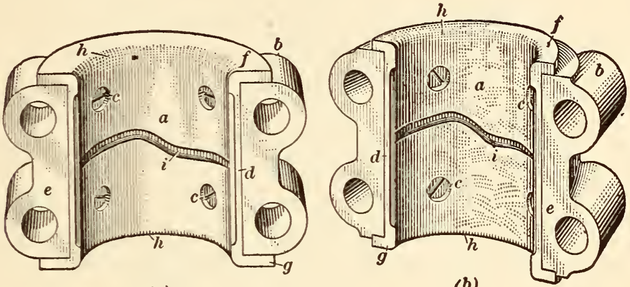
64. Fitting New Bearings to Crankpins.—The following description deals with the various steps to be taken in installing and refitting new bearings to crankpins. In cases where only refitting is necessary, the general procedure will be that described in the sixth and succeeding steps.

1. Secure new bearing bushing halves, or if the bearings are of the cast-in type, secure a new connecting-rod or have the old one rebabbitted. Support the crankshaft as in Fig. 15, where *a* is the shaft, and *b* a bench, furnished with the clamping device *c* for holding one end of the shaft, the other end resting on the horse *d*.

2. Install the bushing halves, or brasses, in their respective seats by tapping them into place with a rawhide hammer. Make sure that they are of a length to fit the seats in the rods and in the caps without buckling.

3. Take care not to distort the brasses while hammering them into place. More cases of bearing trouble are caused from poorly fitting brasses than from any other source.

4. After the brasses have been installed in the caps, they will occupy a position corresponding with that shown in Fig. 16 (*a*), in which *a* is the brass and *b* the cap. The screws *c*, which hold the brass to the cap, should be prick-punched to prevent them from getting loose. This is done by making a small punch mark with a center punch exactly on the dividing line between the head of the screw and the brass. The parting faces *d* of the brass should be filed or faced down to a true, flat surface, even with the parting faces *e* of the cap and of the connecting-rod end, respectively. During the facing-off process, the parting faces should frequently be tested on a surface plate to see that they are perfectly square. The rod end and the cap should be tested individually on the surface plate. Then, each mating rod and cap should be tested together in the manner explained in Arts. 54 and 55.



(*a*) (*b*)

FIG. 16

5. File the end faces *f* and *g* of the brass *a*, Fig. 16 (*a*), until it and the mating brass have the required end play on their particular crankpin. While this end play is being checked, be sure to examine the bearing to see that it has a

relief at *h* corresponding to the fillet on the pin. A tight fillet usually means a bearing burned at one end.

6. In case of a pressure-lubricated bearing, fitted with shims, the next step is to fit the shim tips in the manner illustrated in Fig. 12.

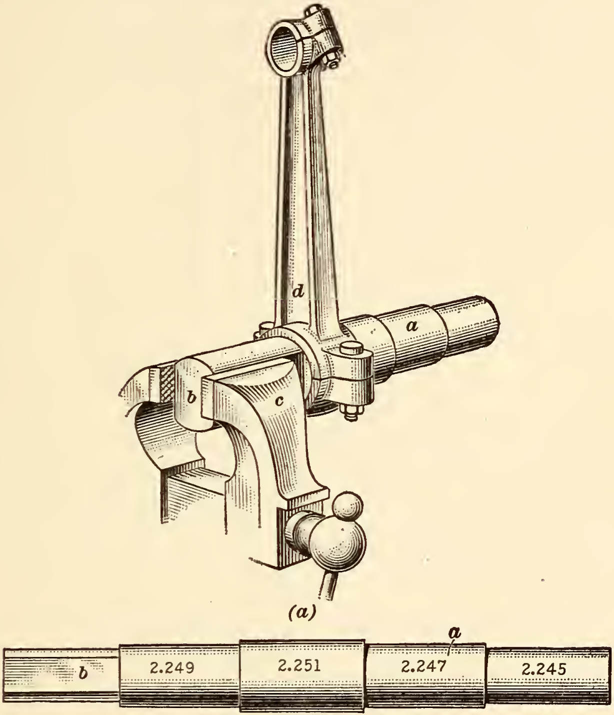
7. The rod and the cap are now ready to have their bearing halves scraped or reamed to the proper fit.

The difference between the bearing caps, shown in Fig. 16, is that the brass *a* in view (*b*) was scraped with a dull scraper. The result was that some of the cuts were too deep, as indicated at the cross-hatched places. View (*a*) shows a brass *a* fitted to size by means of a reamer. In both views *i* is an oil groove.

65. Scraping Old and New Bearings to Fit Crankpin. The bearings may be scraped to fit the crankpin or to fit an arbor of the same diameter. Some operators prefer to have the arbor diameter slightly larger than that of the crankpin. Instead of having one arbor for each size of crankpin, it is preferable to have an arbor divided into four parts of different diameters, as shown in Fig. 17 (*a*) and (*b*). The latter view shows the arbor *a* separately to illustrate more clearly the relative sizes of the separate portions of the arbor. The part *b* is flattened off on two sides in order that the arbor may be held securely in the vise *c*, view (*a*). For arbors of diameters slightly larger than those of the respective crankpins, the procedure of fitting the connecting-rod bearings will be as follows:

1. As an example, a crankpin is chosen with a diameter of say 2.250 inches, measured with an outside micrometer. A piece of cold-rolled shafting or other suitable stock is turned down in a lathe to make an arbor with a diameter lying between 2.2510 and 2.2515 inches. Clamp the arbor in a vise in a position corresponding with that of the arbor *a* in the vise *c*, Fig. 17 (*a*), and proceed to fit the lower bearing of the connecting-rod *d* in the manner explained with reference to splash lubrication in Art. 61. Remove shims or reduce the thickness of the flanges by rubbing the parting faces on emery cloth,

until the thickness of the flanges is reduced to such an extent, that on joining the bearing halves and bolting them together on the arbor, it will be necessary to apply a pull of from 8 to 10 pounds at the upper end of the rod *d* before it will begin to turn. Then unbolt the bearing assembly, apply Prussian blue to the arbor, and again tighten the bolts.



(a)

(b)

Fig. 17

2. Revolve the connecting-rod a few times around the arbor and again unbolt the cap. If the impression left by the color does not cover an area equivalent to 75 per cent of the total bearing area, scrape or ream the bearing until it is properly spotted.

3. In this method of fitting, the rod bearing is scraped to the oversize arbor as if being fitted to its own crankpin. The

arbor, however, being of the proper oversize, automatically takes care of the diametrical clearance required for the oil film.

In case an arbor or a mandrel is not available, the connecting-rod must be fitted to its crankpin. To secure an impression of the Prussian blue, it will be necessary first to remove a sufficient number of shims until the connecting-rod will stick on the crankpin after being clamped in place. Finally, remove the cap, apply the blue, and note the impression.

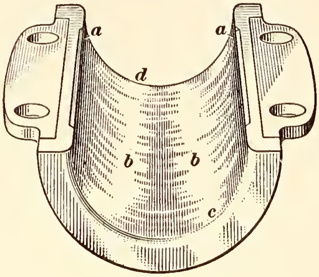


FIG. 18

66. On examining the impression left by the Prussian blue in the preceding test, the operator may find that the high spots on the bearing surface of the bushings lie near the sides of the bearing. That is, there will be contact near the parting lines, while the crankpin or arbor will fail to touch the bottom of the bearing. This condition is roughly indicated in Fig. 18, in which the streaks of darker shade indicate blue color. It is seen that there is a thick covering of color on the narrow strips *a* near the parting lines, while the bottom portions *b* are bare of coloring, or are very thinly covered at spots, an indication that at the latter places there is a lack of contact.

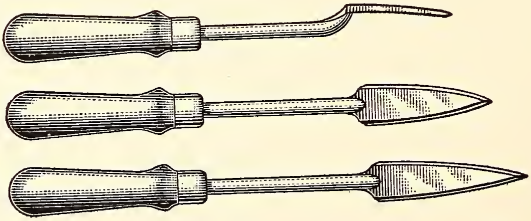


FIG. 19

The process of scraping a bearing is a tedious one, but is not particularly difficult, requiring mainly patience and carefulness to do a good job. The connecting-rod should be clamped in a vise, and the high spots, as designated by the blue coloring, scraped off very carefully with a bearing scraper. These scrapers usually come in sets of three, a common set being shown in Fig. 19. The scraper should be held by two hands as shown in Fig. 20, and only a very fine cut should be made at a time. In the case of new bearings, wherein high spots are indicated by the coloring, the time required to reduce these high spots and obtain an evenly distributed bearing depends very much upon the way in which the scraping is done. If decided rises in the surface are indicated, much time can be saved by scraping larger areas than those actually covered by the colored marks. The scraper must have a very keen cutting edge, and should be sharpened frequently. By trying the connecting-rod and its lower bearing frequently on the crank-pin and then scraping off the high spots as indicated by the coloring marks, a very close fit may be obtained. When the connecting-rod bearing has been properly fitted, the operation

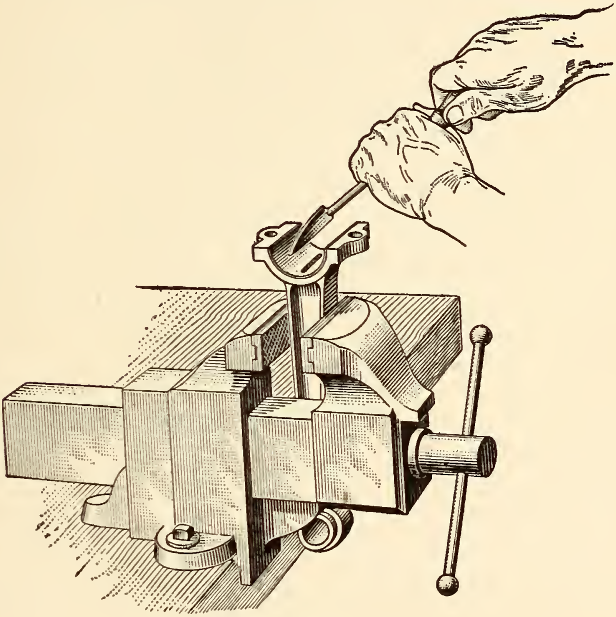


Fig. 20

should be repeated on the bushing in the lower bearing, which should be similarly marked and fitted.

There are on the market bearing lapping compounds, the purpose of which is to produce a more nearly perfect bearing surface than can usually be produced by scraping. In the case of refitting bearings, no scraping whatever is required before the compound is used, whereas with new bearings, it is advisable to scrape them until a 50 per cent bearing surface is obtained.

In scraping out the side portions at *a*, Fig. 18, along the parting line for the purpose of increasing the bottom contact, care must be taken to provide a good contact area along the end portions *c* and *d* of the bearing. This area should be about ½ inch wide and extend clear around the crankpin, its purpose being to prevent any oil leakage at these places. After the bearing has been scraped to provide the required contact area, so that it, when assembled, is just tight enough to require a pull at the end of the connecting-rod of about 2 to 3 pounds to overcome the drag, it should be removed from the mandrel and attached to the crankpin without further fitting.

67. The method of using an arbor for testing bearings, in the manner illustrated in Fig. 17, is especially valuable where the shaft has been removed from the engine. But it can be employed profitably also on overhauling jobs where the crankshaft is disassembled. Besides saving time and exertion, the arbor insures correct spotting and diametrical clearance. The arbor may be utilized on connecting-rod bearings, irrespective of whether pressure or splash lubrication is used.

68. Fitting New Bushing Halves to Seats.—It is always necessary to install one new bushing half or both halves in cases where a main bearing in a small engine is burned or has been subjected to pounding. The particular point to aim at in installing a bushing half is to obtain a good contact with its seat in the cap or in the block. At least one-half of the back surface of the bushing half should make contact with its seat; hence, wherever possible, the contact should be tested by applying Prussian blue to the seat and then moving the bushing half back and forth on its seat to have the color transferred to it.

Bushing halves provided with end flanges should fit snugly, as regards end clearance, but not so tight as to be distorted when fastened down with the screws. It should be possible to tap them into place with light blows from a rawhide hammer; they are not considered as being too loose, if they can be put in place by hand pressure alone. Between the inner faces of the end flanges and the adjoining faces of the cap or of the block there should not be more than .001 inch end play after the bushing half is seated.

After the backs of all the bushing halves have been properly fitted to their seats, they are fastened permanently into place. Then their parting faces are filed flush with the corresponding faces of the cap or of the block, as the case may be.

The next step is to insert the crankshaft and adjust for end play by filing down the flange end of the bushing half intended to receive the end thrust, usually that of the center bearing. On engines where the end play is controlled by thrust bearings or by shims the final adjustment is made by means of suitably arranged screws or by substitution of shims.

69. Spotting Upper Bushing Halves.—At the present stage of fitting, the engine block is supposed to stand in an inverted position on the bench with the crankshaft resting in the upper bushing halves of the main bearings. The purpose of the next step in the process of installing new bearings is to test the contact between the shaft journals and the bearings. The principal steps in this test are as follows:

1. Lift the shaft out of its bearings and cover the journals with a thin coating of Prussian blue, rubbing the blue very thinly over all portions of the journals with a forefinger.
2. Replace the shaft and, while bearing slightly down on it, revolve it several times.
3. Lift out the shaft and note the impressions left on the babbitt faces of the upper bushing halves. It will be found that the high spots of the babbitt surfaces are covered with Prussian blue, proving that only at these places was contact made with the shaft journals.

70. Scraping Upper Bushing Halves.—After the bearings have been spotted, it is necessary to remove the high spots either by means of a reamer or by using a hand scraper, as at *a*, Fig. 21, which shows the inverted engine block *b* with the upper portion of a bearing and the corresponding bushing half *c*. This process of scraping, bluing, revolving, and testing is repeated several times until the blue spots cover a combined area equivalent to about 75 per cent of the total babbitt surface.

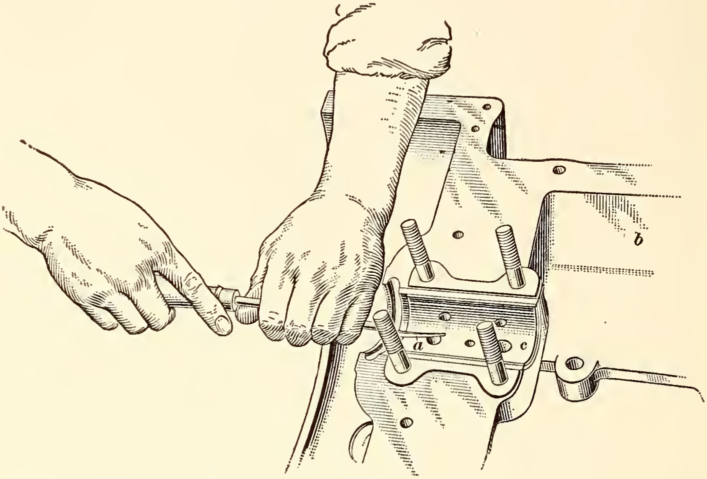


FIG. 21

As this stage is reached the scraping must be done very carefully, only a small amount of babbitt being removed at each setting. If the work is done carelessly, so that at some places too much babbitt is taken off, then the next test will show a diminished contact area.

Wherever possible, the main bearings should be scraped to a fit while the cylinder block is assembled to the crankcase, as in many engines the act of fastening the cylinder block to the crankcase will cause some change in the alinement. By duplicating in this manner the actual working conditions, a subsequent misalinement of the bushings is avoided. For a similar reason a main bearing should be scraped while the flywheel is removed from the crankshaft.

71. Fitting Caps to Main Bearings.—After a 75-per-cent contact area has been obtained for the upper bushing halves the operator may proceed to fit the cap babbitts into contact with the journals, either by filing or lapping the parting faces or by removal of shims. In other words, it is necessary that the babbitt facings in the caps shall make a firm contact with the journals before the Prussian-blue test can begin.

One of the end caps should first be so adjusted that when the bolts are tightened up, the crankshaft can be turned only by means of a crank, applied either at the front or at the rear end in the manner shown in Fig. 22. Here the crank *a* is clamped to the front end of the shaft *b* for the purpose of turning it while the socket wrench *c* is used for tightening the nuts of the cap *d* on the center bearing, the tightening process being continued until the required resistance to motion is felt at the crank handle. Then the cap *d* is removed, a thin coating of

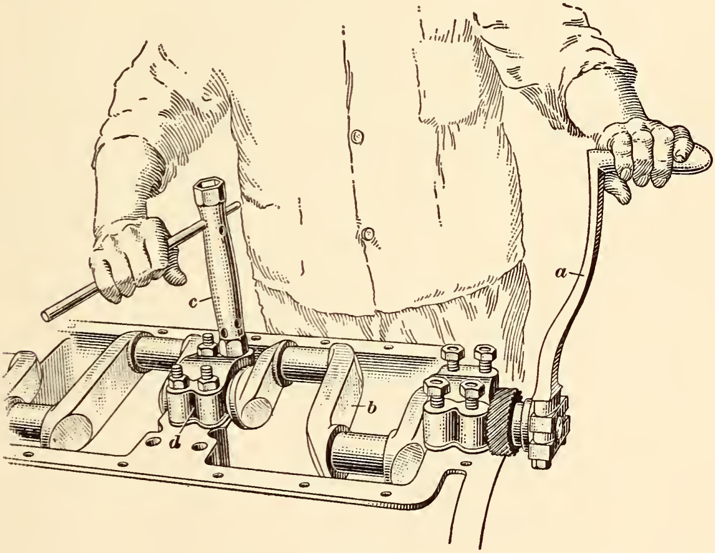


Fig. 22

Prussian blue is applied to the journal, and the cap is made tight again. After the shaft is revolved a few turns, the cap is removed again.

The succeeding steps are performed in the following order:

1. Note the places on the babbitt facing to which blue color has been transferred from the journal.
2. Scrape the blue places on the babbitt facing; test and repeat the scraping until the blue color transferred from the journal covers a total area of not less than 65 to 75 per cent of the babbitt surface.
3. Repeat the operations on the other end bearing.
4. Proceed in the same manner with the center bearing or bearings.

72. Adjusting Bearings for Clearance.—After the upper and the lower bushing halves have been scraped to a good fit, the next step is to adjust the bearing for diametrical clearance. For this purpose the tissue paper or the shim block method may be used. In applying the latter method, the adjustment is made by adding a thin shim under each parting face of the caps. When all the caps are bolted down it should be possible to turn the engine by hand by means of the flywheel, which in the meantime has been attached to the shaft.

When new bushings are being installed, it is advisable to allow less clearance than would be given old bushings. This is because the clearance will gradually increase in the case of new bearings as the bushing halves adjust themselves to their seats in the caps and in the block, respectively.

73. Checking Oil Passages and Grooves.—After the diametrical clearance has been adjusted for each bearing the oil passages and holes in the crankshaft and in the bearings should be cleaned out by means of compressed air for the purpose of removing chips that may have fallen through the holes during the scraping operation.

The oil grooves in the upper and in the lower bushing halves should be examined for burrs and also for ascertaining whether the holes register with the oil-supply holes in the shaft and in the crankcase. Sometimes the bushing halves are supplied without oil holes; hence, this matter should receive careful attention. Similar attention should also be given to babbitt facings that are cast directly into the cap and into the block, as such facings require the drilling of oil holes and the forming of oil grooves in the bearing halves. Oil grooves should have rounded edges, as a sharp edge on a groove may act as a scraper and break up the oil film. Lengthwise oil grooves serve no good purpose in a pressure-lubricated bearing. Radial grooves are all that is necessary to enable the lubricating oil to reach the drilled passage in the connecting-rod leading to the piston pin, whereas a lengthwise groove, especially when extended too near the ends of the bearing, affords an opportunity for the oil to escape at the ends.

COOLING-WATER TROUBLES

74. Prevention of Cooling-Water Troubles.—Cooling-water troubles in the operation of internal-combustion engines are almost invariably caused by the formation of air pockets, or scale or sludge in the water-jackets. Scale and sludge deposits reduce the efficiency of heat transfer from the heated surfaces to the water. If sludge is permitted to accumulate in the water passages, it may interfere with the free flow of water and cause local overheating of engine parts. To prevent the formation of the troublesome deposits the temperature of the cooling water must be kept below that at which the mineral salts and impurities in the water will be precipitated. The discharge temperature should be from 120° to 140° F., but should never exceed 150° F. The reason for this is that impurities of a scale-forming nature, principally calcium and magnesium, are at ordinary temperatures kept in solution in the cooling water by gases contained in the water, chief among which is carbon dioxide. When the temperature of the water rises above 150°, these gases are liberated and escape as soon as the water comes in contact with the atmosphere. The impurities then become insoluble and are deposited in the jacket spaces. If the cooling water used is very hard, the discharge temperature should not exceed 130° F. It should be remembered that the temperature of the cooling water should be low enough to prevent the formation of scale and keep the temperature of the valves, pistons, and cylinders below the danger point, yet at the same time must be high enough to keep the engine at its most efficient working temperature. Hard deposits in the cylinder jackets should be regularly removed by allowing a weak solution of hydrochloric acid, consisting of 1 part of acid to from 10 to 20 parts of water, to stand in the jackets for 12 hours, and then washing out the jackets with warm water. If hydrochloric acid is not available, a solution of 1¼ pounds of ordinary washing soda to 1 gallon of boiling water can be used. Hard water should never be used in the jackets if it can possibly be avoided; if no other water is available, the hard water should be treated by means of chemicals or by passing it through a water-softening system before it is circulated.

75. The method of employing softeners, such as lime or caustic soda, in the cooling water is to make the impurities insoluble and then remove them either by a filtering process or by allowing them to settle out in what is known as a settling basin. If the latter method is employed, some substance, or *coagulant,* is added to the water in order to hasten the settling process. The coagulant generally used is sodium aluminate. In the zeolite softening process the cooling water is passed through a batch of zeolite, a mineral containing sodium. This causes the scale-forming impurities in the water, such as sulphates of calcium and magnesium, to be taken up by the zeolite, whereas the sodium in the zeolite goes into the water and forms sodium sulphate, which is soluble in water and hence does not form scale. One disadvantage of the zeolite treatment of hard water is that it renders the water corrosive; that is, although the water will not form scale, it often produces rust on the inside surfaces of the water-jacket due to oxygen contained in the treated water. One way of preventing the formation of rust is to add to the water an alkaline tannin compound, prepared from liquid spruce, chestnut oak extract, or sulphite cellulose. Specially prepared bricks containing tannin compound are on the market and are introduced into the cooling system by placing them in a wire basket set in the path of the water. Generally 1 pound of tannin brick per 1,000 gallons of water is sufficient to coat the metal surfaces of the jacket with a thin protective layer of iron tannate, thereby preventing corrosion.

Suitable apparatus for cooling the hot water discharged from the engine jackets should be installed to cool the water to the proper temperature before it is recirculated through the jackets. If any make-up water is added to the system it is good practice to treat such water to remove any ingredients that might cause scale deposits. Grease can be removed from cooling water by the addition of a hot solution of lye or sal soda. These solutions are very effective in removing grease but may have a harmful effect on packings, such as are used in pumps.

76. Care must be taken to maintain the water-circulating pump at all times in good working condition, as on this may depend the safe condition of the engine. If a reciprocating plunger pump is used, as is frequently the case in marine internal-combustion engines, leaky pump valves due to accumulation of dirt between the valves and seats should be attended to without delay. Faulty operation of the pump check-valves is generally indicated by irregular flow of circulating water through the overflow, which is under observation by the operator. Reciprocating pumps operating with an air chamber should be checked occasionally to see that there is no lack of air in the chamber, as this may result in knocks and blows in the pump. In case of lack of air, an air valve, known as a snifting valve, attached to the air chamber should be opened slightly, and when the noisy pump operation ceases it should be almost closed. The cooling system should always be vented at the top, so that any entrained air or steam caused by localized heating will have a chance to escape. If air issues from the vent on any one cylinder when starting the engine, it indicates that starting air leaks into the cylinder-head water-jacket. On the other hand, if air escapes from the vent during the regular operation of the engine, it is an indication that compressed air from the combustion chamber leaks into the cylinder jacket because of a cracked cylinder head or liner.

77. If, for any reason, the flow of cooling water through the jackets is interrupted, the engine should be stopped immediately and allowed to cool gradually. Failure of the cooling water or a serious shortage will cause the cylinders and pistons to become excessively hot, often resulting in distortion of the pistons and scoring of the cylinders. To avoid this trouble, modern cooling systems are usually provided with an alarm signal warning the operator of the danger of an insufficient or interrupted water circulation. Cold water should never be pumped through a heated cylinder jacket, as seized pistons and cracked liners or cylinder heads may result. In addition, cooling water that is too cold may cause inefficient combustion of the fuel in the cylinders and may also cool the cylinder lubricating oil to such an extent that efficient lubrication of the cylinders and pistons cannot take place. In cold weather, all circulating water should be drained from all the jackets, water pump, and piping to prevent freezing. If the engine refuses to carry more than from 75 to 90 per cent of full load and all the mechanical parts, including the circulating pump, are functioning properly, and there is no trouble with the fuel oil and the lubricating oil systems, it indicates that there is scale in the water-jackets. Temporary relief may be afforded by increasing the flow of circulating water by speeding up the pump, but this cannot always be accomplished, as many pumps are direct-driven from the engine. When trouble of this nature occurs, it is advisable to stop the engine at the earliest opportunity and remove the scale deposits adhering to the walls of the water-jackets.

78. If the engine is provided with a radiator as part of the cooling system, cooling troubles may be caused by a broken pump, insufficient radiation, water leakage from a loose hose connection, a slipping fan belt, or by dirt or scale obstructing the radiator or the radiator hose. Care must be taken to inspect the hose at regular intervals to make sure that it has not become deteriorated, thereby interfering with the free flow

of the cooling water. Lack of water in the radiator of the cooling system is indicated by the rapid emission of steam, if there is sufficient water to enter the engine jackets; the bottom of the radiator being cold; the overheating and smoking of the engine, followed by laboring, groaning sounds, owing to the oil being burned away faster than it is supplied to the pistons; and, if the engine still continues running, expansion and seizure of the pistons in the cylinders. Trouble from lack of water is due to carelessness in not filling the tank before starting; leakage in radiator, hose, or piping; accidental opening of the drain cock at the lowest point of the circulation system; breakage of the drain cock, etc. The remedies for such troubles are apparent on inspection.

79. If the engine becomes overheated so that the water boils away rapidly, and there is reason to believe that the upper portion of the water-jacket is dry, the engine should be allowed to cool before water is added. An obstruction to the circulation of the cooling water elsewhere than in the radiator will cause the bottom of the radiator to remain cool while the top is probably boiling hot. A slipping fan belt, caused by grease or oil on the belt, may be cleaned with gasoline. If the belt slips because of slack, the fan bracket should at once be shifted until the belt is tightened sufficiently. The presence of scale or sediment in the radiator is indicated when the whole radiator becomes hot or when steam formed in the jacket forces water out of the upper pipe to the radiator, there being no oil on the inside or dirt on the outside of the radiator. Scale will deposit from hard water if the temperature of the water is allowed to approach the boiling point. A very hard scale may form from calcium-chloride anti-freezing mixtures if these are allowed to become supersaturated; that is, when the salt concentration is in excess of that normally carried in a saturated solution.

80. The formation of scale in the radiator reduces the cooling effect on the water, as the scale is a very poor conductor of heat. By proper attention at regular intervals, the formation of scale to such an extent as to become very detrimental to the cooling system can be prevented. The water should be drawn off occasionally and the entire system flushed out, by use of water under pressure from a hose if convenient. The radiator should then be filled with clean water. Every few weeks a solution of ordinary washing soda, in the proportion of a handful of soda to a pail of boiling water, should be poured into the radiator and the engine run for a few hours. The water and soda solution should then be drawn off and the system flushed out thoroughly before fresh water is put in. A radiator that is badly choked with lime scale may be cleaned by the use of a dilute solution of hydrochloric acid in the proportion of about 1 part of acid to 10 parts of water. This solution should be left in the radiator only long enough to loosen the scale, after which it should be drawn off and the radiator washed out. In doing this, a good plan is to disconnect the radiator from the engine, so as to confine the effects of the acid. Scale is not likely to deposit to any great extent in radiators that have thin, flat, vertical tubes, especially if there is rapid forced circulation of the cooling water by a powerful circulating pump.

The hose used for connecting the radiator to the engine jackets should be heavy enough so that it cannot collapse by the suction of the pump, and it should be made of good quality, so that none of the rubber or fabric can work loose. It should be fitted with close-fitting hose clamps, care being taken to slip the hose over the end of the metal pipe connection carefully, or the inner fabric of the hose is liable to be loosened and may fold under and partly or entirely stop the circulation of the water. Gaskets used at the hose joints must be so placed as not to project on the inside and reduce the area of the water passage.

81. Anti-Freezing Mixtures for Engine Radiators.—There are several anti-freezing substances commonly used in radiators of cooling systems: Wood alcohol, glycerine, calcium chloride, and others sold under various trade names. The objection to calcium chloride is that it deposits scale in the radiator water passages. Alcohol vaporizes rapidly and must be often renewed, and glycerine affects the rubber of the hose connections. The use of kerosene as anti-freeze is not recommended on account of its inflammable character. A mixture of alcohol and glycerine in proportion of 1 quart of alcohol, 1 quart of glycerine, and 4 quarts of water is recommended for a temperature not lower than 10° F. below zero, but more alcohol must be added from time to time to make up for evaporation. When glycerine alone is used, one part of glycerine to three parts of water is a common mixture.

MISCELLANEOUS ENGINE TROUBLES

CAUSES OF ENGINE OVERHEATING

82. Operating an internal-combustion engine at excessive temperatures is generally destructive to the engine, as the extreme heat thins out the cylinder oil, and the engine parts wear more rapidly than under normal temperature conditions.

An engine that overheats should be checked systematically, beginning first with the most obvious or common causes, and then proceeding gradually to the less common and less easily determined causes. In checking the following points, special reference has been made to a gasoline engine of the automotive type, such as used on trucks, buses, and tractors.

1. Water too low in radiator. Check the radiator for leaks by filling it up to a point just below the overflow, and then running the engine. Examine the radiator from the front and back, the hose connections at the top and bottom, and the cylinder jacket. Also, look underneath the engine for any signs of dripping water. The proper repair for radiator leaks is to remove the radiator and solder it, although an emergency procedure is to pour into the radiator a good liquid sealing compound. Flaxseed, corn meal, and other similar solids should not be put into the radiator under any circumstances, as they will not only increase the overheating by stopping up the water passages, but will likely cause damage to the radiator.

Leaks at the hose connections can usually be eliminated by tightening up the clamp screws, or by installing new clamps or lengths of hose.

2. Improper lubrication. First, with the engine running, look at the oil gage to see whether the oil pump is working.

The gage gives no indication of the amount of oil in the sump, so the next step is to stop the engine and check the oil in the reservoir. If the oil supply is sufficient, note the condition of the oil. If it is very thin, and appears to be mixed with gasoline, drain it out, and refill the reservoir with clean oil. If the gage does not register, either the oil line leading to the gage is blocked, or the pump is not functioning properly. The oil line should first be cleared, and then an examination made of the pump.

3. Fan belt slipping. A fan belt may slip because it is loose or oily, or the shaft binds in its bearings. The fan should be checked by attempting to spin it by hand. If a **V**-shaped belt is used, and the belt is working properly, the fan can be turned only with difficulty. If the fan turns easily, or there is too much slack in the belt, the belt should be adjusted. If the belt is too slack when the limit of the adjustment is reached, or if the belt is oily, a new belt should be installed. In an emergency an oily belt can be made to pull better by wiping it as clean as possible, and then sprinkling powdered chalk on its inner side. If the fan turns too hard, the belt is too tight, or the fan bearings are binding, probably because of a lack of lubrication. A belt adjustment will remove the first trouble, while the second can usually be overcome by lubricating the bearings. When time is available, the fan bearings should be removed and cleaned thoroughly.

4. Radiator hose rotten or thin. A defective radiator hose can usually be detected by an inspection of the outer surface, although it often happens that the outside appearance is very misleading. A good piece of hose will be springy when pinched with the fingers, and will return to its orginal shape as soon as the pressure is released. On the other hand, if the hose feels thin, soggy, or inelastic, it should be removed. Such a hose will likely collapse under the suction of the water pump, and shut off the circulation. Sometimes the lining breaks away from the body of the hose and acts as a shut-off valve. Consequently, the only sure way to determine whether the hose is in good condition when a stubborn case of overheating is encountered, is to remove and examine it. A temporary repair on a leaky

piece of hose may be made by winding two or more layers of electrician's tape around the hose throughout its entire length. If the hose has disintegrated to such an extent that it will not supply the necessary support for the tape, it may first be reinforced with several turns of wire or even thin pieces of wood may be laid like splints along the sides of the hose before the tape is wound in place.

5. Frozen radiator. Steam issuing from a radiator during freezing weather usually indicates one of two things, namely, that the radiator is frozen, or if alcohol is used as an anti-freezing agent, that the radiator has been left partly covered long enough to cause the alcohol to evaporate. To determine whether the radiator is frozen, feel the radiator at the bottom and also the lower hose connection leading to the engine. If the radiator is cold at the bottom, but hot at the top, there is no circulation and freezing has very likely taken place. Frozen radiators are more common with cooling systems fitted with thermostats, because the water does not circulate until it has become heated, and in many cases, the water freezes in the lower part of the radiator, thus preventing circulation and causing steaming. With such systems it is particularly important that the engine be warmed up somewhat before it is operated in an exposed place in freezing weather, unless the cooling system contains anti-freeze mixture.

To thaw out a frozen radiator, it is best to move the engine to a warm place and leave it there until the radiator thaws out by itself without the application of heat, although hot water may be poured slowly over the bottom part of the radiator until circulation is once more resumed.

If the radiator has been standing in a cold place long enough to freeze solid, it should be removed and immersed in a tank of hot water. After the radiator is thawed out, it should be tested for leaks. If the cooling system is provided with a thermostat, the thermostat disks should next be removed and tested. These are usually located in an opening in the upper radiator tank, and are held in place by a cap that is fastened to the radiator by screws. The disks can be tested by holding them over a slow heat, such as a gas flame, until they are hot, at which time the sides should bulge out. If the disks do not expand under the heat treatment, they should be discarded and replaced by new ones. In most cases a single thermostatic unit is employed instead of disks, but this can be tested in the same way as described for the disks.

Anti-freeze solution in the radiator after the weather has warmed up will also cause an engine to boil over. This may or may not be an indication of overheating, depending on the kind of anti-freeze solution, alcohol, for instance, vaporizing at temperatures considerably below the boiling point of water.

6. Radiator clogged or of wrong type. A radiator may be partly blocked up by dirt, rust, or other foreign matter, but unless this has been allowed to accumulate for some time, the radiator can usually be cleaned out satisfactorily with washing soda, or one of the many solutions now on the market for that purpose. When soda is used, it should first be dissolved in hot water in the proportions of 1 pound of soda to each gallon of water and then poured into the radiator. Run the engine for several hours after it has warmed up properly, and then open the drain cocks and remove the lower hose connection. When the solution has drained out, the radiator should be flushed thoroughly with fresh water.

If the soda treatment does not clean out the radiator, the water passages are probably blocked up by a hard scale. In some cases, the scale can be removed by dismounting the radiator, plugging the upper and lower openings, pouring into the radiator from 2 to 4 quarts of hydrochloric acid solution and plugging the filler opening. The solution consists of 1 part of hydrochloric acid to 10 parts of water. The radiator should be laid down flat, and then tipped up at alternate ends so that the solution will surge to all parts of the radiator. The acid should not be left in the radiator for over 5 minutes. If this treatment fails to remove the obstruction, the only recourse is the installation of a new radiator core. There are high-pressure radiator cleaners now on the market that flush out rust and dirt from the cooling system.

A radiator may occasionally be encountered in which the external passages through the core are stopped up with mud or dirt. In such a case, the radiator should be cleaned by a stream of water from a hose, applied from the rear of the radiator. Do not use pressure on the water, as damage to the core will likely be the result. Let the mud soak off gradually, using just enough pressure to carry the water through the radiator.

7. Insufficient circulation through the engine hood. The openings, or louvers, in the sides of the hood form an important part of the cooling system, as they make possible a free circulation of air through the hood. These openings, however, should be closed during very cold weather, in order to prevent the escape of heat around the engine, and maintain as nearly a normal operating temperature as possible.

8. Brakes set too tight. Overheating will result if the brakes are set so tight as to drag on the drums and cause overloading of the engine.

9. Too much friction in the engine. A new engine or one recently overhauled will often run at temperatures above normal because of the tightness of the parts. The engine should be cranked by hand, with the sparkplugs removed, and if it can be turned over only with difficulty, there is excessive friction in the moving parts. Some of the things most likely to cause such friction are improperly fitted piston rings; rings of too great tension, either by themselves or in conjunction with inner rings; or bearings set up without sufficient clearance.

10. Ignition poor or late. When the cause of engine overheating cannot be located in the cooling system, a check should be made on the ignition. If the ignition is irregular or weak, as might be caused by pitted or dirty contact points, weak breaker springs, or dirty or improperly set sparkplugs, a greater demand will be made on the engine, and overheating will result. A late spark is also a not uncommon cause of an overheated engine, and may occur in an engine that was originally timed properly, because of wear of the rubbing block on the circuit breaker, or the sticking of the automatic advance. In such a case, the explosion occurs so late that there is only a small drop in the temperature of the burning charge between the time that ignition occurs and the time that the exhaust valve opens; consequently, the heat due to the burning charge is much greater than is

the case with a properly timed, early ignition, and the cooling system is unable to carry the heat off as fast as it is generated.

The obvious remedy is to run at all times with the spark advanced as far as conditions will permit.

11. Fuel mixture too rich or too lean. After checking the ignition system without favorable results, attention should be given to the gasoline system. Either a too rich or a too weak mixture is a slow-burning non-effective mixture, and the result is that the engine must be overworked to produce the desired power, and overheating follows.

12. Slipping clutch. On an automotive type gas engine a slipping clutch will cause the engine to overheat, because the engine must be kept at high speed all of the time in order to maintain the required vehicle speed. To test for a slipping clutch, slow the vehicle down to a speed of about 12 miles per hour, or less, with the engine in high gear, and then push down quickly on the accelerator. The engine should immediately pick up speed, the speed of the vehicle picking up at the same time. If the engine starts to race, but there is no appreciable increase in the vehicle speed, the clutch is slipping, and should be overhauled at the earliest opportunity.

13. Pump not turning. This trouble is experienced occasionally during the winter months because of the water in the pump freezing and causing the impeller pin to shear off. Trouble is sometimes experienced with wear between the pump impeller and its housing, resulting in little or no circulation of the water.

Pump trouble is not easy to locate, as the drive shaft continues to run as usual, and there is no external indication that anything is wrong. Probably the quickest method of checking the action of the pump is to remove the upper hose connection at the radiator end, fill the radiator with water until it starts to run out of the open end of the hose, and then run the engine. If the pump is working the water should issue from the hose in a powerful stream. If the water does not flow from the hose, the pump should be disassembled.

GASKET TROUBLES

83. Cylinder-Gasket Troubles.—The joints between the cylinder head and the cylinder of stationary internal-combustion engines are kept tight by a specially prepared copper-asbestos gasket. When the gasket is damaged by overheating or excessive pressure, water from the jacket leaks either to the outside or into the cylinder. The latter is the more serious leak of the two, as it interferes with the running of the engine by corroding the points of contact on the sparkplug and the valve seats and stems, and prevents proper lubrication of the piston and cylinder. In a stationary engine provided with a cooling system in which the discharge jacket water overflows into a funnel, leaking toward the cylinder is generally indicated by splashing of the cooling water at the overflow pipe when the explosion takes place. As a general rule, leakage toward the combustion chamber causes the engine to come to a stop in a short time.

In most cases, the blowing out of a gasket is caused by the combustion pressure opening the joint between the gasket surfaces, the gasket being heated and partly destroyed, and allowing water to enter the combustion chamber. A partial or complete stoppage of the cooling-water supply or the clogging of the water spaces with lime or similar deposits will also result in the overheating of the cylinder and consequent damage to the packings.

As soon as a leak of water from a faulty gasket develops, preparations should be made to renew the gasket at the first opportunity. If the leak is to the outside, the operation of the engine is generally not interfered with, and it is not necessary to shut down the engine. The replacement can be postponed until a convenient time.

84. There are various reasons for the failure of gaskets. They may have been made of unsuitable material, the bolts may have been tightened irregularly, or there may have been defects in the gaskets originally. In modern engines with bolted-on cylinder heads, copper-asbestos gaskets are used. These consist of an asbestos center cut to shape by dies and surrounded by thin sheet copper pressed over the asbestos. This type of gasket can be used repeatedly, if care is taken not to bend or break it when removing it. It is usually cheaper in the end to use a new gasket, but if the old one is to be used, it should be annealed by heating it to a red heat and then allowing it to cool slowly, before being put in place. Another widely used form of gasket is the wire-woven asbestos gasket, consisting of asbestos having a fine wire gauze woven into it to give it strength. In an emergency, gaskets for cylinder heads may be made from heavy manila wrapping paper coated on both sides with shellac just before they are put in place.

85. Installing New Gasket.—To renew a gasket, remove the nuts or bolts that hold the valve chamber or cylinder head to the cylinder, and carefully clean the metal surfaces of any parts of the old gasket, using a scraper or a similar tool, but being careful not to mar the surfaces. If the gasket has blown out, it is advisable to examine the condition of the surfaces and ascertain whether they are true and have not been warped by heat or drawn out of shape by excessive tightening of the bolts or studs.

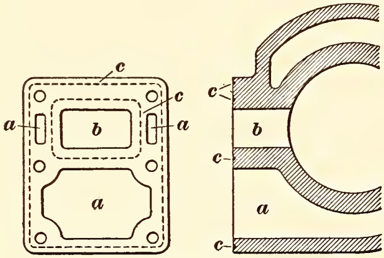


Fig. 23

If it is found that the metal surfaces are not true, they must be put in good condition by filing, or, better, by scraping, use being made of a surface plate covered with a thin layer of red lead and oil for determining the high spots. In case studs are used in the cylinder, they must, of course, be removed before the surface on the cylinder can be trued up. The scraping must be continued until the test with the surface plate shows that the gasket will have a perfectly straight and evenly bearing metal surface around the water ports *a* and combustion-chamber port *b*, Fig. 23, to rest against. The portion of the surface surrounding the port *b*, where the pressure is highest, should bear a little harder than the rest of the surface.

86. After the faces of the flanges have been put in proper condition, cut the new gasket from a suitable thickness of asbestos sheet, being careful to have the opening that corresponds with the port communicating with the combustion chamber large enough to allow no portion of the edge of this hole in the gasket to project over the joint. Such projections of the gasket material will become incandescent and produce back firing or premature combustion of the charge. Put back in place the studs that hold the valve casing to the cylinder, apply a coat of flake graphite to the side of the gasket that is to rest against the valve casing, and carefully slide the gasket over the studs until it bears against the metal surface. Then attach the valve or cylinder head to the cylinder, screw the nuts on the studs, and tighten them gradually and evenly.

87. Many times a cylinder-head gasket will leak when the retaining screws have been screwed down tight, even with a new gasket, because the pressure was not exerted evenly throughout the entire surface of the gasket. After the cylinder head is put in place on the cylinder body, with the gasket properly inserted between, the capscrews should be put in and screwed down lightly, alternating from a screw on one side of the cylinder head to one on the other. When the screws are all fairly tight; the operation should be repeated, alternating as before, until the screws are firmly set in place. After everything has been put in order, start the engine and run it under a light load or idle, until it begins to warm up, when it is found that the nuts can be tightened up still more. This should be done promptly, as neglect to take up any expansion resulting from the heat of the combustion may cause the new gasket to become leaky soon after it has been put in.

88. While the faces of the flanges must be true and straight, it does not follow that they should be as smooth as glass. Experience has shown that a grooved surface gives much better results than a perfectly smooth one, although many manufacturers seem to take great pains to make the surfaces as smooth as possible. In many cases, troublesome joints have been permanently cured by the judicious application of

grooves in the metal surfaces. The packing fills the grooves and prevents the escape of gas between the surfaces. Fig. 23 shows, by dotted lines, the positions of the grooves *c*. In some engines concentric grooves are cut in the top of the cylinder and in the cylinder head; that is, one groove in the cylinder and two in the head. These grooves should not come opposite each other when the cylinder and the head are assembled, but the groove in the cylinder should come midway between the grooves in the head. On large engines a single groove is sometimes machined in the top of the cylinder in which a copper-asbestos gasket is laid, no grooves being cut in the cylinder head.

89. As the material employed for gaskets is usually copper-bound asbestos, or asbestos with an insertion of wire gauze, a knife or a pair of scissors makes very little impression on the latter, but tin snips may be used to advantage. It can be cut out very readily if the sheet is laid on the cylinder head and hammered carefully over the sharp edges of the casting with the flat face of a light, round-peen hammer. The holes for the bolts can be cut in like manner with the round peen. Great care should be exercised not to pull out any wires from gaskets in which wire gauze is used. The wires should be cut off very carefully.

If the material used is ordinary asbestos sheet $\frac{1}{100}$, $\frac{1}{64}$, $\frac{1}{32}$, or even $\frac{1}{16}$ inch thick, it should be thoroughly soaked in linseed oil, either raw or boiled, and dusted carefully with powdered or flake graphite, or with graphite foundry facing that contains talc, etc., which is a very good substitute. It is a good plan to let this dry a little while in the air, until it becomes sufficiently dry to prevent it from running freely. It should not, however, be allowed to get too dry.

90. After the gasket has been put in place, the holding nuts should be screwed down carefully, by going over them several times and screwing down opposite nuts instead of adjoining ones. The engine should then be started and run a few minutes, and the circulating water turned off, in order to heat up the engine and assist in drying out the oil or any dampness in the gasket. The nuts should then be tightened carefully, when the water may safely be turned on. If these directions are followed closely, and the gasket is not defective, it should last a long time. The oxidation of the linseed oil will make the gasket tough, and if it is dusted with graphite every time the cylinder head is removed it should be very durable.

In places where gaskets are not exposed to great heat, as between the upper and lower halves of the crankcase, a good, heavy quality of paper can be used. The paper is held in place and cut out to the proper form by tapping it along the edges of the crankcase with a peening hammer. Both sides of the paper should be given a good coat of shellac before it is placed in the engine.

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